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EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES

Report No. 90-48-K

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ABSTRACT

The work reported here was carried out under the auspices of the Repair Materials Task Group representing different areas within Ontario Hydro.

Based on literature review and information from suppliers, seven epoxies and three cement-based products, as well as control concrete and neat cement grout for comparison, were selected and tested for compressive strength, modulus of rupture, thermal coefficient of expansion, viscosity, and tack, open and hard times. Composite specimens to simulate concrete to concrete repairs were tested at various ages to determine bond and shear strength for different applications and curing conditions. Freeze/thaw resistance of the composite specimens was also assessed.

In spite of wide variation in the test results of the composite specimens, the use of some of the bonding agents provided an improved adhesion. In general, the epoxy bonding agents did not show any better performance.

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	SELECTION OF REPAIR MATERIALS	1
3.0	TEST PARAMETERS	1
	3.1 Repair Material Specimens	2
	3.2 Composite Specimens	2
4.0	PREPARATION OF TEST SPECIMENS	2
	4.1 Control Concrete	2
	4.2 Composite Specimens	2
	4.3 Repair Material Specimens	3
5.0	CURING AND TEST CONDITIONS	3
	5.1 Composite Specimens	3
	5.1.1 23°C Saturated-Surface Dry	3
	5.1.2 23°C Dry	3
	5.1.3 10°C Dry	3
	5.1.4 30°C Dry	3
	5.2 Freeze/Thaw	4
	5.3 Repair Material (Bonding Agent) Specimens	4
	5.3.1 Thermal Coefficient of Expansion and Modulus of Rupture	4
	5.3.2 Compressive Strength	4
6.0	TESTS AND RESULTS	4
	6.1 Repair Material (Bonding Agent) Specimens	4
	6.2 Viscosity	4
	6.3 Tack, Open and Hard Times	4
	6.4 Coefficient of Thermal Expansion	5
	6.5 Compressive Strength	5
	6.6 Modulus of Rupture	5
	6.7 Compressive Bond Strength	5
	6.8 Shear Strength	6
	6.9 Freeze/Thaw Tests	7
7.0	DISCUSSION	7
8.0	CONCLUSIONS	10
9.0	RECOMMENDATIONS	10
REFERENCES		12
FIGURES	1-10	13
TABLES	1-21	23
APPENDICES		44
DISTRIBUTION		last page

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To Dr. D. Mills
Director of Research

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES

1.0 INTRODUCTION

The repair of concrete has always presented problems. One of the main difficulties has been to achieve sufficient bond between old and new concrete so as to resist drying shrinkage and subsequent movement caused by wetting and drying and/or heating and cooling. This is particularly true when thin sections are used to join new to existing concrete.

Over the past few years, information on the use of bonding agents for repair work has appeared in technical literature/1-7/. Two main types of materials are promoted, one based on latex emulsions in a cement slurry and the other based on epoxy resins.

A limited laboratory study was carried out to determine the effectiveness of these materials.

2.0 SELECTION OF REPAIR MATERIALS

Based on the technical information provided by manufacturers, ten bonding agents, neat cement grout and control concrete were selected for testing. The selected materials represent a cross-section of generic types: seven epoxies, three latexes and neat cement grout. Among the important features considered during this review were the availability and suitability of products for various environmental conditions.

The materials, identified as Product 1 to 11, are listed in Table 1 including the generic names and mix proportions. Control concrete was cast for comparative purposes (identified as Products 12 & 13 - Table 1).

3.0 TEST PARAMETERS

Two series of test specimens were prepared, one to test the physical characteristics of the bonding agents and the other to test the properties of the bonding agents in a simulated concrete repair.

3.1 Repair Material Specimens

The physical properties of the bonding agents were determined by testing appropriate specimens of cubes (50 mm^3) and prisms (25 x 25 x 125 mm). The properties tested were viscosity, tack, open and hard times[1] (for epoxies only), coefficient of thermal expansion, compressive strength, and modulus of rupture. Test methods are described in Appendix A.

3.2 Composite Specimens

Composite specimens were used to represent simulated concrete repair. The specimens, made by applying the bonding agent to the hardened concrete and casting fresh concrete against it, were cylinders, 75 mm diameter x 150 mm, and concrete slabs, 406 x 406 x 150 mm. Test methods are outlined in Appendix B. The actual method of specimen preparation depended on the intended application of the bonding agent and fresh concrete as described in Section 4.2.

The specimens were made and tested at various ages to determine the bond and shear strength under different application and curing conditions. All 28-day test results were compared with those of the control concrete specimens cured at 23°C and 50% relative humidity. The freeze/thaw resistance of the composite specimens was also determined.

4.0 PREPARATION OF TEST SPECIMENS

In total, 1,010 specimens were tested: 68 control specimens, 660 composite specimens and 282 specimens of the bonding agents. The number of specimens prepared for the control concrete, composite, and repair material, for each series of tests, are contained in Tables 3 through 7.

4.1 Control Concrete

Since a large quantity of concrete was required to carry out the test program, prepackaged concrete was used to make all the control specimens, including the half sections for the composite specimens. A 25-MPa class concrete made with Normal Portland cement (Type 10) and 16 mm maximum size aggregate was used. This material, supplied by King Paving, was previously tested and approved for use by Ontario Hydro. The mix proportions and the physical properties of the concrete used for the different castings are given in Table 2. The average 28-day compressive strength of the hardened concrete was 26.4 MPa (Appendix C, Product 13).

---

1. See Table 8, Note 2, for definition of tack, open and hard times.

4.2 Composite Specimens

The half-slab and cylindrical composite specimens were cast using the control concrete. These half sections were initially cured for 28 days at 23°C and 100% relative humidity. Prior to applying a bonding agent, the bond surface of the concrete was sandblasted to remove any laitance and to roughen the surface. The specimens were then stored in their respective environments prior to placing the bonding agent and casting fresh concrete. The configuration and preparation of the composite specimens are shown in Figures 1 and 2.

All the bonding agents and base concrete were conditioned at the required test temperature (10°, 23° and 32°C). The cement-based and epoxy bonding agents were mixed for a minimum of 4 minutes and 3 minutes, respectively, using a Jiffler mixer. After mixing, the epoxy bonding agent was placed against the dry hardened concrete, brushed into place, and allowed to become tacky before fresh concrete was cast against it (Figure 3). For one group of specimens, the epoxy was applied and the fresh concrete was placed immediately. Water was brushed onto the hardened concrete surface shortly before applying the cement-based bonding agent. Fresh concrete was placed immediately, except in one group of specimens, which had cement-based bonding agent applied and the fresh concrete placed 45 minutes later (see Mix 2, Table 7 for properties of concrete). The workability (ie, slump) of the fresh concrete was varied to assess the effect on the performance of the bonding agents.

4.3 Repair Material Specimens

The bonding agents were mixed following the procedure described in Section 4.2. The specimens were made using the bonding agents alone. The specimens were cured as described in Section 5.0

5.0 CURING AND TEST CONDITIONS

Composite specimens and repair material (bonding agent) specimens were made from each product. Each set of specimens was cured under one of the conditions described below.

5.1 Composite Specimens

5.1.1 23°C Saturated-Surface Dry

The cement-based bonding agents were applied against dampened concrete surfaces. Fresh concrete was then placed and the specimens were stored at 23°C and 50% relative humidity until tested. However, one group of specimens was stored at 23°C and 100% relative humidity until tested at 11 months.

5.1.2 23°C Dry

The epoxy bonding agents were applied against dry concrete surfaces. Fresh concrete was then placed and the specimens were stored at 23°C and 50% relative humidity until tested. One group of specimens was stored at 23°C and 100% relative humidity until tested at 11 months.

5.1.3 10°C Dry

The bonding agents were stored, mixed and placed against a dry or damp concrete surface at 10°C. The fresh concrete was made at 23°C, then placed against the hardened concrete at 10°C. The specimens were cured at 10°C until tested. All specimens were tested at 10°C.

5.1.4 32°C Dry

The bonding agents were stored, mixed and placed against a dry or damp concrete surface at 32°C. The fresh concrete was made at 23°C, then placed against the hardened concrete at 32°C. The specimens were cured at 32°C until tested. All specimens were tested at 32°C.

5.2 Freeze/Thaw

The bonding agents were applied to a dry or damp surface at 23°C. The specimens were cured for a minimum of 14 days at 23°C and 50% relative humidity prior to testing.

5.3 Repair Material (Bonding Agent) Specimens

Test methods followed to determine the viscosity and tack, open and hard times of the epoxies are outlined in Appendix A. These tests were performed by conditioning and testing the epoxies at temperatures of 10°, 23° and 32°C.

5.3.1 Thermal Coefficient of Expansion and Modulus of Rupture

All specimens were prepared at 23°C and 50% relative humidity. The cement-based bonding agents were cured at 23°C wet, and the epoxy bonding agents were cured at 23°C dry until tested.

5.3.2 Compressive Strength

All specimens were made at 23°C and 50% relative humidity. The epoxies were stored at 23°C and 50% relative humidity, while the cement-based bonding agents were stored at 23°C and 100% relative humidity until tested.

6.0 TESTS AND RESULTS

6.1 Repair Material (Bonding Agent) Specimens

The results of the tests on the repair materials are described below. Where applicable, the 28-day results were compared with those of the control concrete cured at 23°C and 100% relative humidity.

6.2 Viscosity

Seven epoxy bonding agents were tested for measurement of mixed viscosity at ambient and material temperatures of 10°, 23° and 32°C. The results of these tests are shown in Figure 4. It is apparent from readings taken at different spindle speeds that most of the epoxies are thixotropic to various degrees, so the results reported were taken generally at one speed (50 rpm) to allow for more useful comparisons. The Monobond epoxy, which is more viscous than the other materials, could not be measured at this speed.

The viscosity of the epoxies ranged from 580 to 125,000 cps at 23°C as a result of the different chemical formulations. At lower temperature (10°C), the viscosity of the epoxies increased significantly (2210 to 790,000 cps). At higher temperature (32°C), the reduction in viscosity varied with each product (320 to 82,000 cps). With some materials (eg, Anvil Bond), it was difficult to obtain an adequate film build-up for the epoxy to be effective, particularly on a vertical concrete surface.

6.3 Tack, Open and Hard Times

All epoxies were tested for tack, open and hard times at 10°, 23° and 32°C. The results of these tests are shown in Table 8 and Figure 5. Generally, the time to reach the various stages of cure increased significantly with decreasing temperature. At higher temperatures, the transition times reduced, and with some materials there was little difference in time to reach the tack, open and hard times. Where these materials are used at higher temperatures, caution should be exercised to prevent the bonding agent acting as a debonder.

6.4 Coefficient of Thermal Expansion

The coefficient of thermal expansion for each material tested at two temperature cycles (23° to -25°C and 23° to 100°C) is shown in Figure 6. For the 23° to -25°C temperature range, the thermal coefficient varied from between 7×10^{-6} mm/mm per °C for Product 1 (a cement-based bonding agent) to as high as 85×10^{-6} mm/mm per °C for Product 4 (an epoxy). For the 23° to 100°C temperature range, the thermal coefficient of each material increased and ranged from 10×10^{-6} to 120×10^{-6} mm/mm per °C. For comparison, the thermal coefficient for Portland cement concrete varied from 4×10^{-6} to 8×10^{-6} mm/mm per °C at the two temperature ranges.

6.5 Compressive Strength

The compressive strength of the bonding agents, tested at 23°C, 50% and 100% relative humidity, is summarized in Tables 9 and 10. The 28-day compressive strength of the bonding agents ranged from 12.0 to 88.1 MPa, with most materials developing higher strength than the control concrete (Table 9). Generally, results showed little strength increase between the 7- and 28-day curing. For the epoxy materials cured at 23°C, there was little difference in strength development at 50% and 100% relative humidity. However, the cement-based bonding agents generally developed 17% to 35% higher strengths when cured at 23°C and 100% relative humidity than when cured at 23°C and 50% relative humidity.

6.6 Modulus of Rupture

Figure 7 contains the 14-day test results. Cement-based bonding agents developed flexural strengths of less than 10 MPa. The flexural strength of most epoxies ranged from 20 to 80 MPa, with the exception of Nitobond where the material creeped significantly under load and developed no strength.

6.7 Compressive Bond Strength

The compressive bond strength of the composite specimens tested at various ages is summarized in Tables 11 to 16 and Appendix C. The composite specimens exhibited lower bond strength than that of the control concrete. The test results at 28 days were scattered, ranging from 4% to 78% of the control concrete (Table 14). A comparison of each material, tested at 28 days under different temperatures and using different concrete slumps, is shown in Appendix C.

The 28-day composite specimens made at 23°C with a 75-100 mm slump[2] were compared with the other specimens made at different slumps and ambient temperatures (Table 14). The following observations were made:

(a) The bond strength of all the cement-based grouts was generally similar to that of the composite specimens made with a 75-100 mm slump, regardless of the increase in slump of the concrete. However, the bond strength typically decreased at 10°C and increased at 30°C. The results did not vary by more than 10% under the above conditions.

It is interesting to note that the concrete-to-concrete bond strength was similar at 23°C, regardless of increase in slump of the concrete. However, the bond strength was significantly reduced at both lower and higher ambient temperatures.

---

2. Epoxy was allowed to reach tacky stage before placing fresh concrete. Cement-based bonding agents were applied and fresh concrete immediately placed.

(b) Five of the epoxies (Products 3, 4, 5, 6 and 10) showed an increase of 5% to 47% in bond strength with increasing slump. Two epoxies (Products 2 and 7) showed a decrease of 15% to 31% in bond strength. The same general trends were observed at the higher and lower test temperatures.

When comparing the epoxy and cement bonding agents, the following observations were made:

(a) Although the results were scattered, the epoxy and cement-based bonding agents tended to perform similarly. (Tables 11 to 13).

(b) A reduction in bond strength, ranging from 17% to 33%, occurred in the cement-based bonding agents where there was a delay between applying the bonding agents and casting the fresh concrete (Table 15).

(c) There was a reduction in bond strength ranging from 67% to 91% when epoxy was applied to the hardened concrete and fresh concrete was placed before allowing the epoxy to become tacky (Table 16). Generally, it appears that maximum bond strength is achieved when the epoxy is allowed to become tacky before placing the fresh concrete.

6.8 Shear Strength

The shear strength of the composite specimens tested at various ages at 23°C for both vertical- and horizontal-cast slabs is listed in Tables 17 and 18, and shown in Figures 8 and 9, and Appendix D. The epoxy bonding agents were allowed to reach their tacky stage before placing the fresh concrete, whereas fresh concrete was placed immediately after applying the cement-based bonding agents.

The shear strength test results at 28 days were scattered, ranging from 35% to 102% (vertically cast slabs) and 37% to 107% (horizontally cast slabs) when compared to the control concrete. For comparison, the results of the shear strength of each material tested at various ages are summarized in Appendix D.

For the vertically and horizontally cast slabs, the cement based grouts developed higher shear strengths than the epoxies. For the cement-based grouts, the shear strength of the horizontal slabs was slightly higher than that of the vertical slabs. The difference in results for the vertical and horizontal slabs when using the epoxies was scattered.

It is apparent from the results that if the epoxies were not allowed to reach their tack stage prior to casting the vertical slabs, significantly lower shear strengths would develop. This would result from the fresh concrete abrading the surface epoxy during placement.

A series of both vertically and horizontally cast specimens were stored at 23°C and 100% relative humidity for 11 months. The results are summarized in Figure 9. When compared with the 28-day test results at 23°C and 50% relative humidity, all specimens stored for 11 months at 23°C and 100% relative

humidity developed higher shear strengths. In general, continued immersion had no detrimental effect on the performance of the bonding agents. However, two materials (Products 2 and 3) developed lower shear strengths for the vertically cast slabs (ie, approximately 50% of shear strength).

6.9 Freeze/Thaw Tests

The results of the freeze/thaw tests are summarized in Tables 19 and 20, and in Figure 10. Compared to the 28-day old control concrete, the cement-based grouts (Products 1, 8, 9, 11 and 12) showed no reduction in shear strength. Six of the epoxy grouts (Products 2, 3, 4, 5, 7 and 10) had lower shear strengths ranging from 13% to 93% of the 28-day old, control concrete. One material (Product 6) developed a higher shear strength. Only two epoxy bonding agents (Products 6 and 10) developed higher shear strengths than the lowest result for the cement-based materials. It is interesting to note that the reduction in shear strength could not be identified by the pulse velocity measurements (Table 20).

When compared to the control concrete subjected to 300 freeze/thaw cycles, all specimens with the exception of Products 9 and 11 developed lower shear strengths. The test results for all materials were scattered, ranging from 13% to 132% of the control concrete. The shear strength of the composite specimens prior to and after 300 freeze/thaw cycles is shown in Tables 19 and 20 for comparison.

It is apparent that the epoxies did not generally provide any advantage over cement-based bonding agents when exposed to freeze/thaw cycles.

7.0 DISCUSSION

It has been the practice either to use no bonding agent and rely on the preparation of the surface of the base concrete or to use a cement slurry. Both of these techniques give excellent results in the laboratory, but field results have been disappointing. This may be because it is difficult to ensure that the prepared bonding surfaces are sufficiently saturated to achieve full hydration of the repair material at the interface and hence optimum bond between the repair material and parent concrete. If the surfaces are too wet, bond strengths will be reduced. Delays in placing the cement slurry and applying the fresh concrete also may result in lower bond strength. Because of this, polymer and epoxy bonding agents are often used to ensure a good bond under site conditions.

Where the concrete surface to be repaired is accessible, polymer latex bonding agents and neat cement grout are simpler to use than epoxy resins. Advantages of polymer-based materials over neat cement are their greater workability at lower water-to-cement ratios and their reduced permeability.

Bond strengths of polymer latex and neat cement bonding agents are similar to that of epoxy when properly applied with good workmanship and attention to detail. However, under severe drying conditions, the "working time" for

polymer latex and cement bonding agents can be too short to ensure a good bond between the repair material and the hardened concrete. Epoxy bonding agents are more widely used because they have adequate pot life and open time to permit flexibility of timing in field application conditions. However, if fresh concrete is placed too late after the epoxy has been applied, bond strengths will be significantly reduced. Also, surface temperature, relative humidity and dew point should always be taken into account when epoxy bonding agents are selected, to avoid improper curing and/or loss of bond strength. For example, when hot and humid air comes in contact with cold concrete surfaces, condensation may interfere with adhesion, making the epoxy bonding agent less effective.

It must be appreciated that the bond at the interface between the concrete and repair material is likely to be subjected to considerable stress from changes in moisture content, freeze/thaw, temperature range, force of gravity, and sometimes vibration. However, when properly used, both epoxy and latex bonding agents help to mitigate the inevitable effects of variation in workmanship and site conditions and thus to improve bond.

Viscosity and tack, open and hard times of the epoxies increased with decreasing temperatures and decreased with increasing temperatures. At the higher temperatures, the decrease in viscosity of some epoxies may prevent sufficient film buildup (such as on vertical surfaces), thus reducing their effectiveness to produce adequate bond. Particular attention should be paid to the shorter working times of the epoxies to prevent obtaining a bond breaker. The coefficient of thermal expansion of the epoxies was higher than that of the cement-based bonding agents.

With the exception of Product 4, the compressive strength of all bonding agents was generally significantly higher than that of the control concrete.

Excluding Product 4, which creeped significantly under a low load, the modulus of rupture of epoxies was higher than that of the control concrete. All cement-based bonding agents had similar flexural strength to that of the control concrete.

The compressive bond strength of the composite specimens was lower than that of the control concrete. For the cement-based bonding agents, generally the bond strengths were not adversely affected by changing the slump of the fresh concrete. However, lowering the curing temperature to 10°C resulted in a decrease in bond strength, whereas raising the curing temperature resulted in an increase in bond strength.

A similar trend in results was observed with the epoxies, although two performed poorly under certain conditions. Generally, the epoxy and cement-based bonding agents performed the same, although the results were scattered.

A delay between applying the cement-based bonding agent and casting fresh concrete or, in the case of epoxies, failing to allow the material to reach its tacky state generally resulted in a reduction in bond strength.

For the vertically and horizontally cast slabs, the cement grouts generally developed higher shear strengths than the epoxies. When specimens were immersed in water for 11 months, there tended to be no detrimental effect on the performance of the bonding agents.

When subjected to 300 freeze/thaw cycles, most composite specimens developed lower shear strength than that of the control concrete. Overall, the cement-based bonding agents had better resistance to freeze/thaw cycles than the epoxies.

8.0 CONCLUSIONS

In comparison to the control concrete, the composite specimens showed a wide variance in performance. A summary of the test results is given in Table 21. The performance of the materials was classified as questionable if their bond or shear strength was less than 50% of the 28-day control or their compressive strength was less than 80% of the control. Of the materials tested as composites, all cement-based bonding agents (Products 1, 8, 9, 11 and 12) and four epoxies (Products 3, 6, 7 and 10) performed well under most of the testing environments, although Product 3 was questionable after freeze/thaw cycling. Based on the above criteria, the performance of Products 2, 4, and 5 was questionable under most test conditions.

In spite of wide variation in the test results of the composite specimens, the use of some of the bonding agents provided an improved adhesion. In general, the epoxy bonding agents did not show any better performance.

9.0 RECOMMENDATIONS

Where cement-based bonding agents are used, it is important that the bonding agent be applied just prior to placing the fresh concrete; otherwise, significant reductions in bond strength may result. Also, the hardened concrete surface should be saturated-surface dry.

Where epoxy bonding agents are used, it is important that the concrete surface be dry and the epoxies in most cases be allowed to become tacky prior to placing the fresh concrete; otherwise, significant reductions in bond strength may result due to:

(a) Emulsification of the water in the fresh concrete affecting the physical characteristics of the epoxies.

(b) Epoxy being abraded from the hardened concrete surface during the placing of fresh concrete.

Although this is a general rule for using epoxies, the manufacturer should be consulted regarding the particular product being used.

A recommended procedure for using bonding agents is included in Appendix E.

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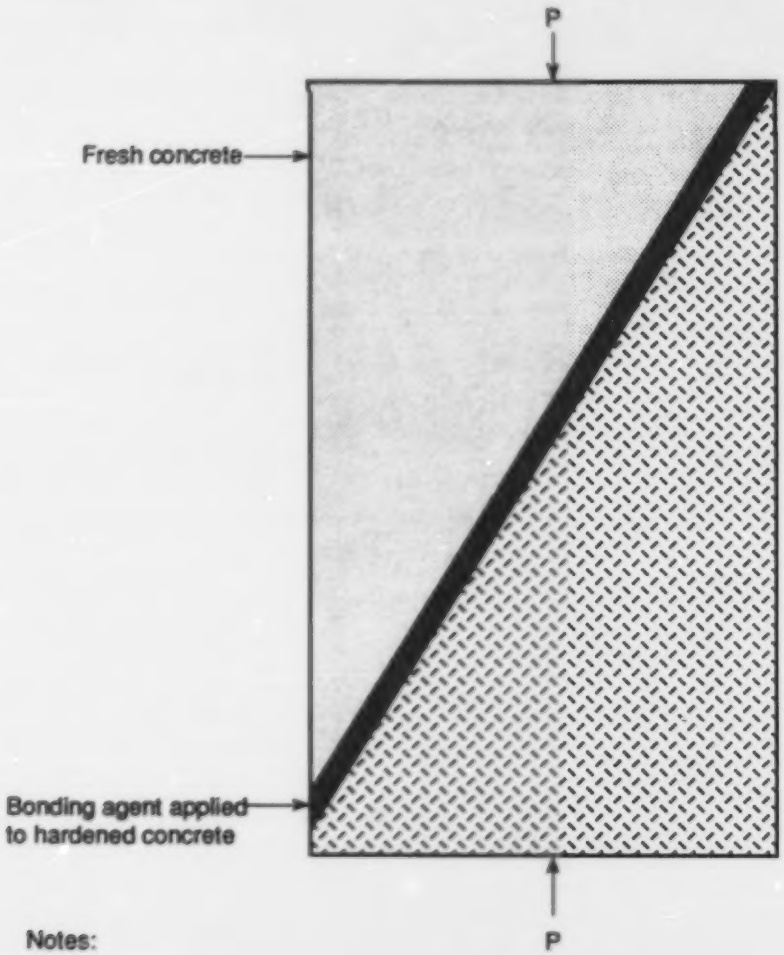


Notes:

(1) All concrete surfaces were sandblasted prior to applying bonding agent.

(2) Bonding agent was applied in accordance with manufacturer's recommendations.

(3) The influence of fresh concrete characteristics and temperature was determined by casting the composite halves of the specimens under the following conditions:

(a) 23°C - 25 MPa concrete - 75 - 100 mm slump
- 150 mm slump
- 240 mm slump

(b) 10°C - 25 MPa concrete - 75 - 100 mm slump

(c) 30°C- 25 MPa concrete - 75 - 100 mm slump.

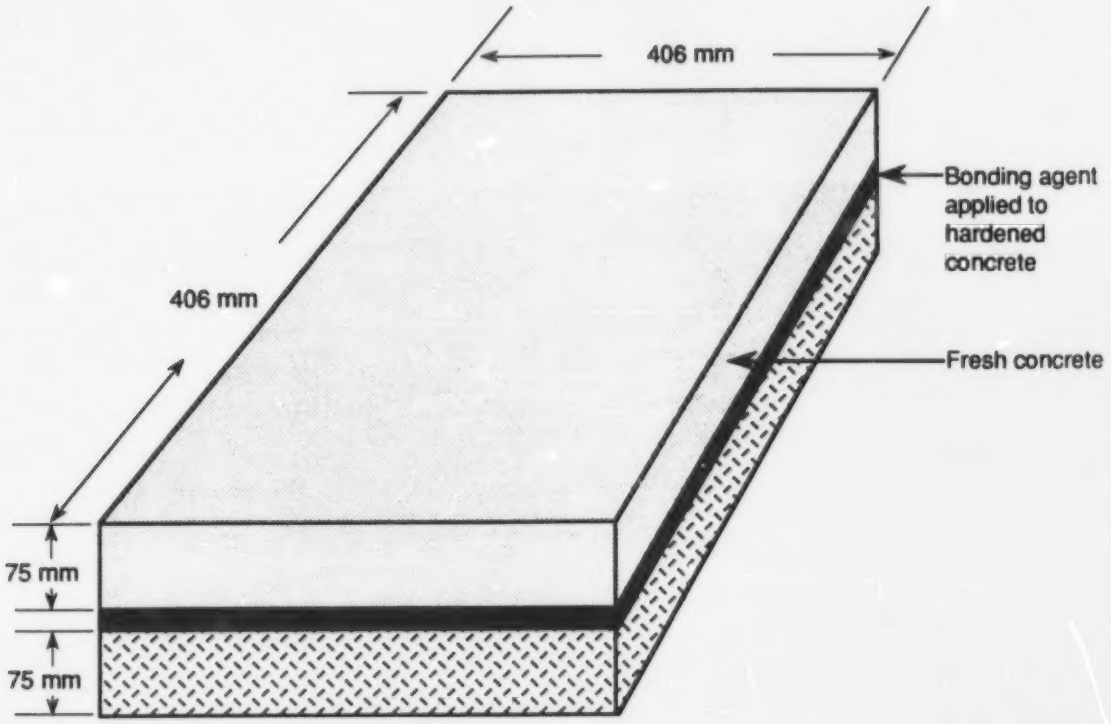
(4) Specimens were tested in accordance with ASTM C 882.

(5) Cylinder dimensions 75 mm dia x 150 mm.

FIGURE 1

PREPARATION OF COMPOSITE SPECIMENS FOR BOND STRENGTH TEST

178905-RD
McWitcz 2



Notes:

(1) All concrete surfaces were sandblasted prior to applying bonding agent.

(2) Bonding agent was applied in accordance with manufacturer's recommendations.

(3) Fresh concrete was cast against hardened concrete after applying bonding agent.

(4) Concrete slabs were cut to the dimensions required for testing in shear.

(5) One series of specimens was tested for freeze/thaw resistance in accordance with ASTM C 666 Procedure A. At the completion of freeze/thaw tests, the specimens were tested in shear.

(6) Specimens were tested in shear in accordance with CRDC C 89-64 modified.

(7) The failure load and failure mode were recorded.

(8) Specimen dimensions - 406 x 406 x 150 mm.

FIGURE 2

PREPARATION OF COMPOSITE SPECIMENS FOR SHEAR STRENGTH TEST

All bonding agents were brushed on to horizontal and vertical concrete surfaces.

Fresh concrete was placed immediately after applying the cement-based bonding agent and after the epoxy bondingagent had become tacky.

FIGURE 3

PLACEMENT OF BONDING AGENT AND FRESH CONCRETE

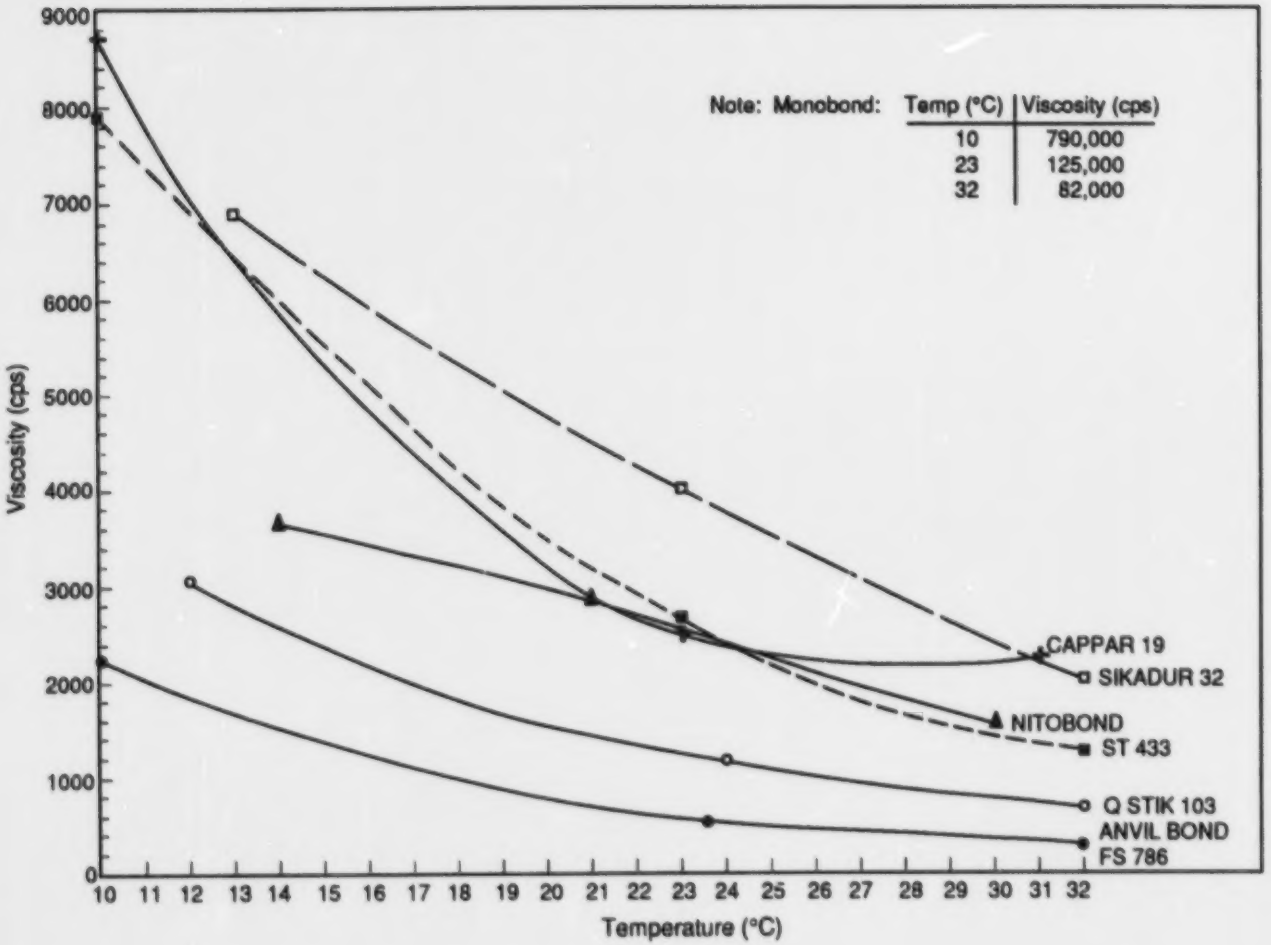


FIGURE 4

EFFECT OF AMBIENT TEMPERATURE ON VISCOSITY OF EPOXY BONDING AGENTS

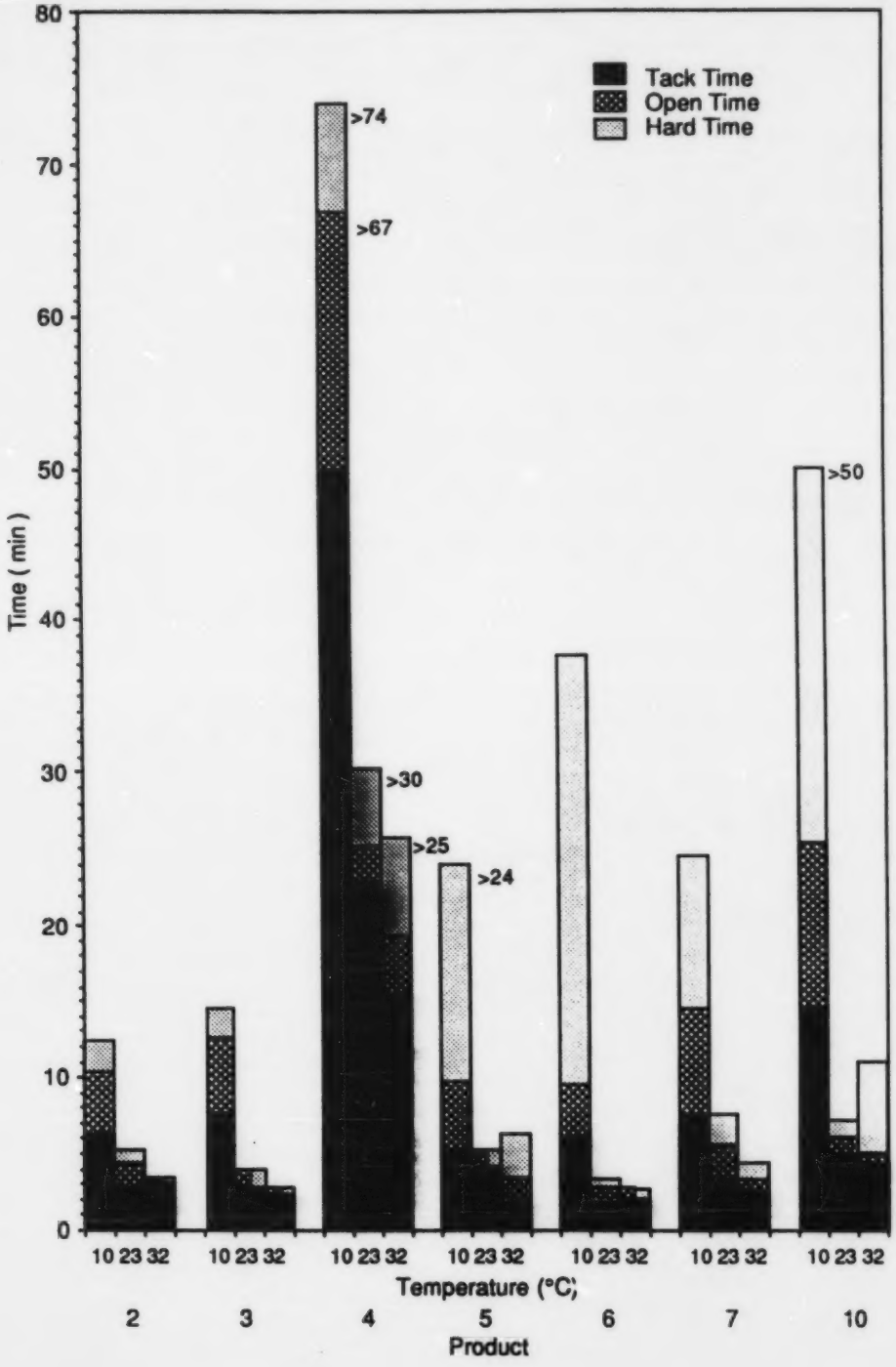


FIGURE 5

EFFECT OF TEMPERATURE VARIATION ON TACK, OPEN AND HARD TIMES OF EPOXY BONDING AGENTS

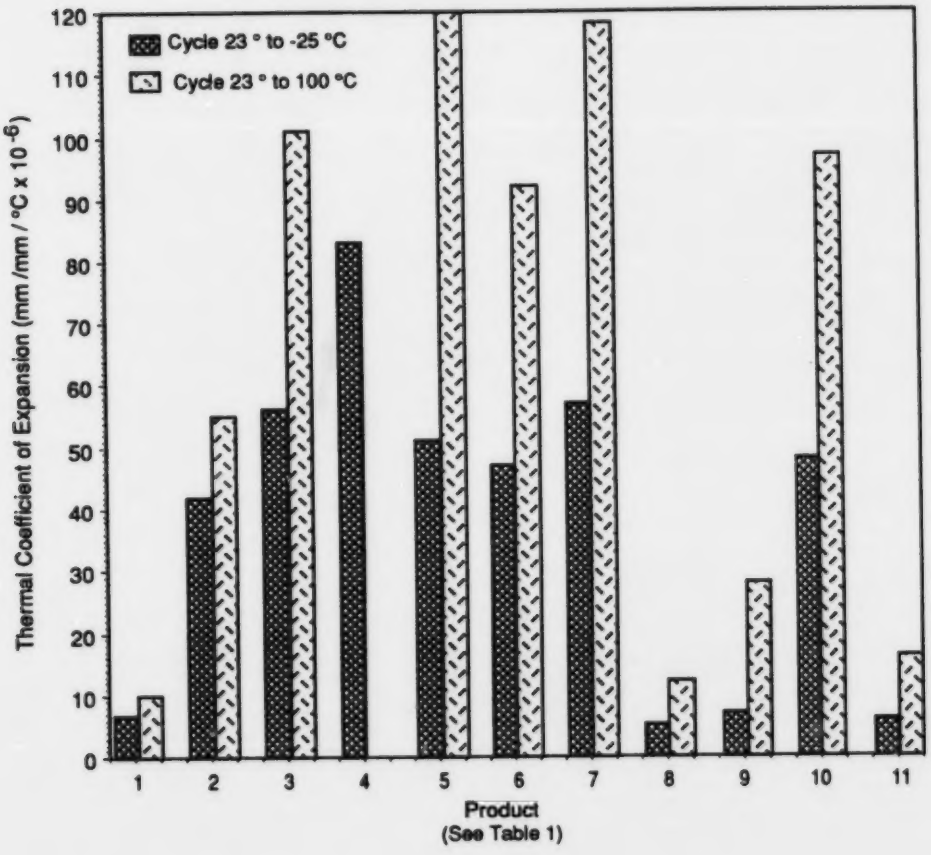
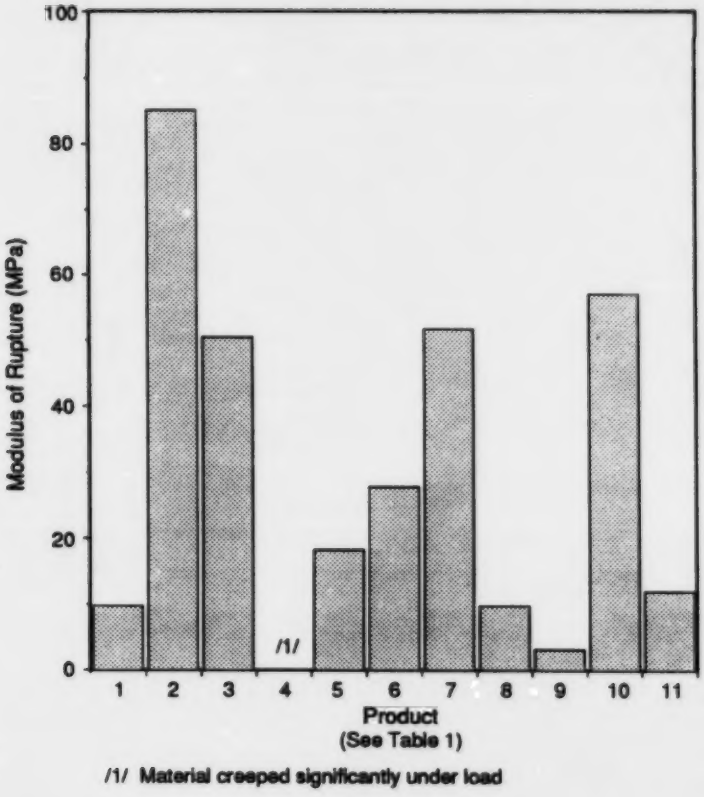


FIGURE 6

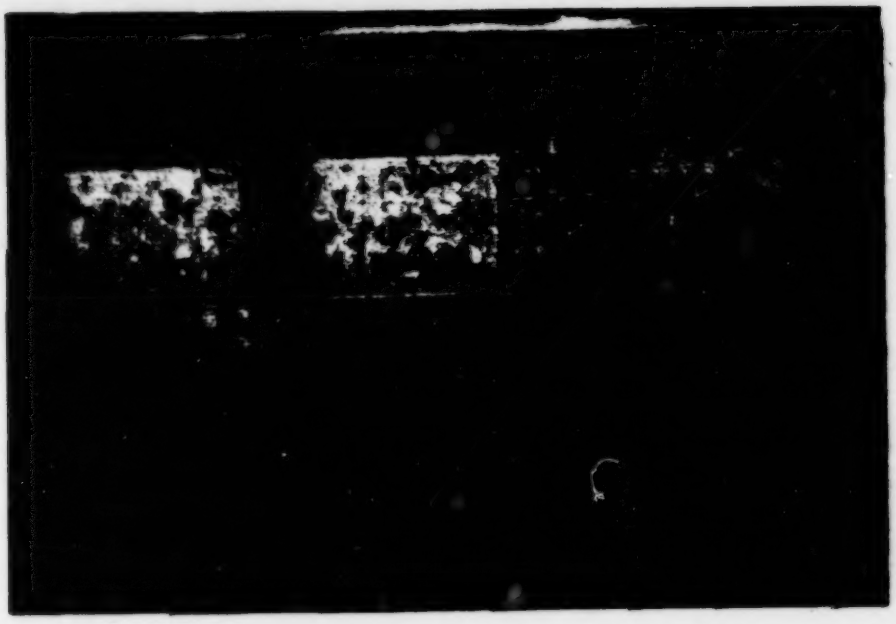
THERMAL COEFFICIENT OF EXPANSION



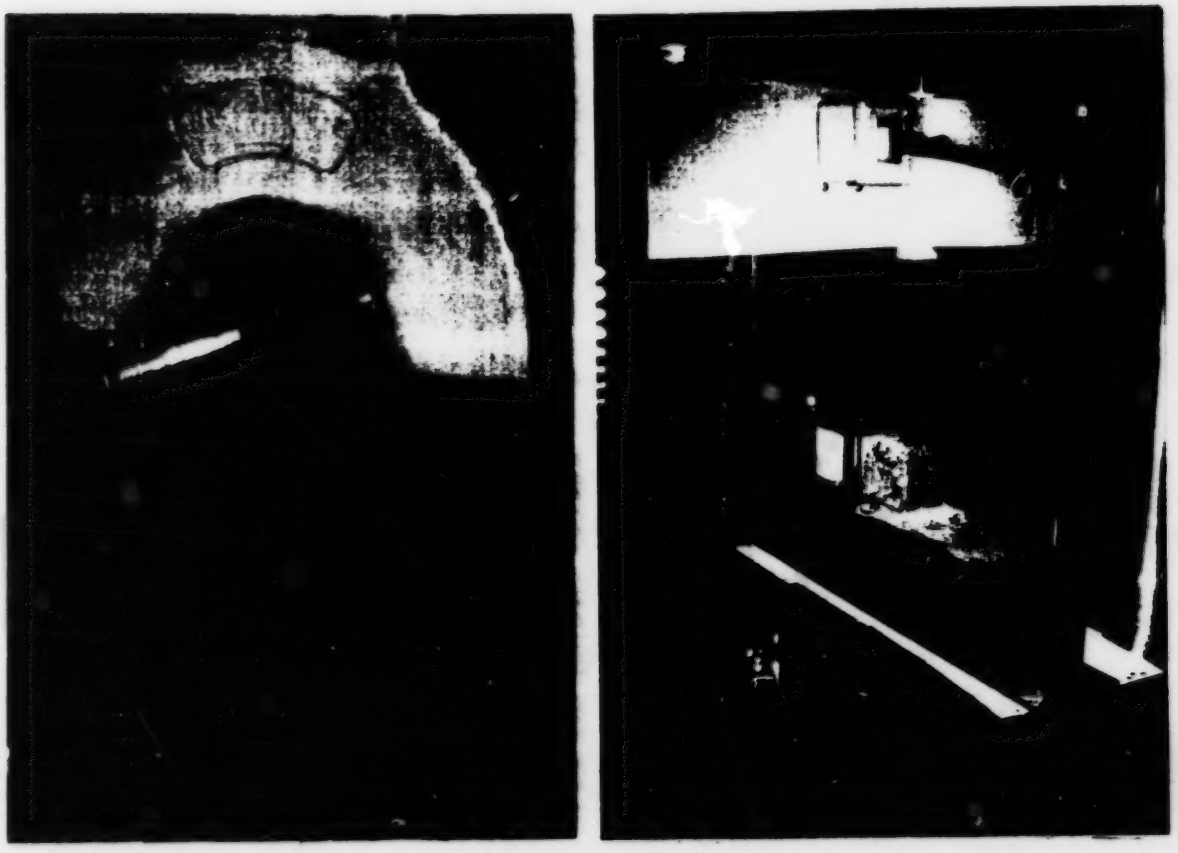
/1/ Material creeped significantly under load

FIGURE 7

MODULUS OF RUPTURE ASTM C 78
AGE - 14 DAYS



Concrete slabs (406 mm x 406 mm x 150 mm) were saw-cut into smaller prisms (100 mm x 100 mm x 150 mm) prior to testing in shear.



Testing of specimens in shear CRDC C89-64 modified

FIGURE 8

TESTING OF BONDING AGENTS IN SHEAR

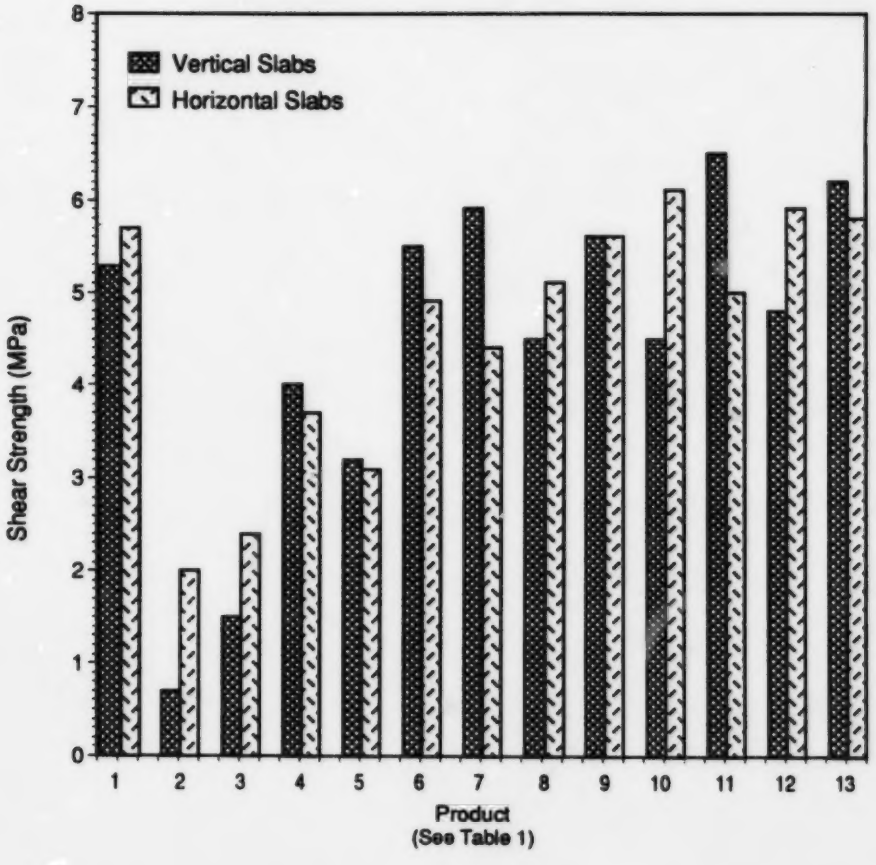


FIGURE 9

SHEAR STRENGTH VERTICAL AND HORIZONTAL SLABS
11 MONTHS AT 23° C AND 100% rh

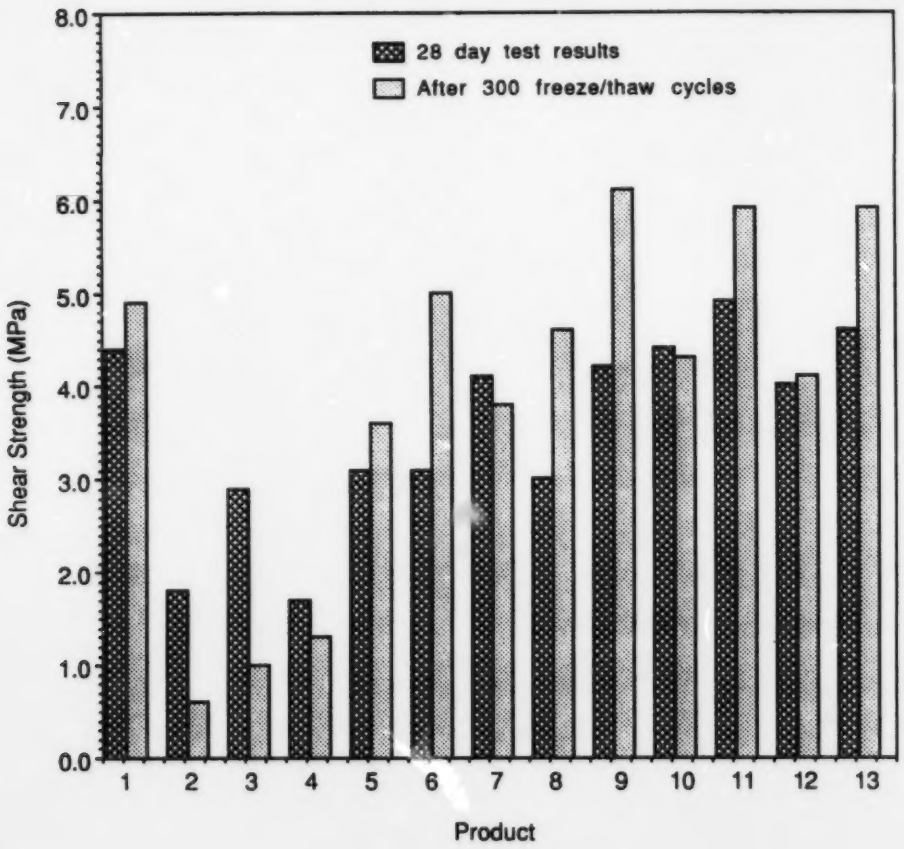


FIGURE 10

SHEAR STRENGTH OF COMPOSITE SPECIMENS PRIOR TO AND AFTER 300 FREEZE/THAW CYCLES

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TABLE 1

EVALUATION OF BONDING AGENTS FOR REPAIR OF CONCRETE STRUCTURES
MIX PROPORTIONS OF BONDING AGENTS

			Mix Proportions					
Product #	Material	Manufacturer	Epoxy (By Volume)		Latex	Cement	Concrete	Water
			Component A	Component B	(g)	(g)	Sand (g)	(mL)
1	Acryl Set	Masterbuilders	-	-	506	908	908	-
2	Anvil Bond F5-786	Masterbuilders	1	1	-	-	-	-
3	Sikadur 32 Hi Mod	Sika	1	1	-	-	-	-
4	Nitobond	Fosroc	2	1	-	-	-	-
5	Monobond	McNaughton Brooks	1	1	-	-	-	-
6	Cappar 19	Cappar	4	1	-	-	-	-
7	ST 433	Sternson	2	1	-	-	-	-
8	Sikacem	Sika	-	-	185	680	680	185
9	Neat Cement	-	-	-	-	1000	-	400
10	Q Stick 103	Chemque	4	1	-	-	-	-
11	Intralock	Meadows	-	-	227	1135	567	227
12	Conc./Conc.	See Table 2 for mix proportions of the concrete						
13	Control Concrete							

TABLE 2

CONTROL CONCRETE MIX PROPORTIONS

Mix[1]	Proportions For 30 kg Bag of Prepackaged Concrete								
	Type 10 Cement kg	Coarse Aggregate kg	Fine Aggregate kg	AEA ml	Water kg	Mighty 150 Super Superplasticizer (mL)	Slump (mm)	Unit Mass kg/m^3	% Air Gross
1 (Initial)	4.8	14.4	10.8	2.0	2.75	-	150	2308	5.4
2 (at 45 min)	4.8	14.4	10.8	2.0	2.75	-	75	2329	4.7
3 (Initial)	4.9	14.4	10.9	2.0	2.75	10.0	240	2319	4.8

[1] Physical characteristics of the concrete were taken initially and 45 minutes after mixing. The fresh characteristics of the concrete were varied to determine the effect on the bond strength of the different bonding agents.

TABLE 3

NUMBER OF REPAIR MATERIAL SPECIMENS PREPARED AND TESTED UNDER VARIOUS CURING CONDITIONS

Test	Product Identification	Test Conditions					Total Number of Specimens
		10°C	23°C	32°C	23°C to -25°C	23°C to 100°C	
Viscosity Brookfield RVT Viscometer	2 - Anvil Bond	2	2	2	-	-	6
	3 - Sikadur 32	2	2	2	-	-	6
	4 - Nitobond	2	2	2	-	-	6
	5 - Monobond	2	2	2	-	-	6
	6 - Cappar 19	2	2	2	-	-	6
	7 - ST 433	2	2	2	-	-	6
	10 - Q Stick 103	2	2	2	-	-	6
Dry Time Recorder (Tack, Open and Hard Times)	2 - Anvil Bond	2	2	2	-	-	6
	3 - Sikadur 32	2	2	2	-	-	6
	4 - Nitobond	2	2	2	-	-	6
	5 - Monobond	2	2	2	-	-	6
	6 - Cappar 19	2	2	2	-	-	6
	7 - ST 433	2	2	2	-	-	6
	10 - Q Stick 103	2	2	2	-	-	6
ASTM C531 Thermal Coefficient of Expansion	1 - Acryl Set	-	-	-	2	2	4
	2 - Anvil Bond	-	-	-	2	2	4
	3 - Sikadur 32	-	-	-	2	2	4
	4 - Nitobond	-	-	-	2	2	4
	5 - Monobond	-	-	-	2	2	4
	6 - Cappar 19	-	-	-	2	2	4
	7 - ST 433	-	-	-	2	2	4
	8 - Sikacem	-	-	-	2	2	4
	9 - Neat Cement	-	-	-	2	2	4
	10 - Q Stick 103	-	-	-	2	2	4
	11 - Intralock	-	-	-	2	2	4
	12 - Control Concrete	-	-	-	2	2	4

Note: Where (-) is shown, no specimen was made.

TABLE 4

NUMBER OF REPAIR MATERIAL SPECIMENS PREPARED AND TESTED UNDER VARIOUS CURING CONDITIONS

Test	Product Identification	Compressive and Flexural Strength[1] Curing Condition and Test Ages (Days)							Total Number of Specimens
		23°C, 50% rh				23°C, 100% rh			
		1	7	14[1]	28	1	7	28	
ASTM C109 Compressive Strength	1 - Acryl Set	2	2	2	2	2	2	2	14
	2 - Anvil Bond	2	2	2	2	2	2	2	14
	3 - Sikadur 32	2	2	2	2	2	2	2	14
	4 - Nitobond	2	2	2	2	2	2	2	14
	5 - Monobond	2	2	2	2	2	2	2	14
	6 - Cappar 19	2	2	2	2	2	2	2	14
	7 - ST 433	2	2	2	2	2	2	2	14
	8 - Sikacem	2	2	2	2	2	2	2	14
	9 - Neat Cement	2	2	2	2	2	2	2	14
	10 - Q Stick 103	2	2	2	2	2	2	2	14
	11 - Intralock	2	2	2	2	2	2	2	14
ASTM C39	13 - Control Concrete	2	2	2	2	2	2	2	14

[1] Specimens tested in accordance with ASTM C78

TABLE 5

NUMBER OF COMPOSITE SPECIMENS PREPARED AND TESTED UNDER VARIOUS CURING CONDITIONS

Test	Product Identification	75 - 100 mm Slump Concrete[4] Curing Condition and Test Ages (Days)												150 mm Slump Concrete[4]		240 mm Slump Concrete[4]		Total Number
		23°C[1]			23°C[2,3]			10°C[1]			30°C[1]			23°C[1]		23°C[1]		
		3	7	28	3	7	28	3	7	28	3	7	28	7	28	7	28	
ASTM C882 Bond Strength	1 - Acryl Set	-	-	-	4	4	4	2	2	2	2	2	2	2	2	2	2	32
	2 - Anvil Bond	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	3 - Sikadur 32	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	4 - Nitobond	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	5 - Monobond	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	6 - Capper 19	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	7 - ST 433	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	32
	8 - Sikacem	-	-	-	4	4	4	2	2	2	2	2	2	2	2	2	2	32
	9 - Neat Cement	-	-	-	4	4	4	2	2	2	2	2	2	2	2	2	2	32
	10 - Q Stick 103			2	2	2	2	2	2	2	2	2	2	2	2	2	2	26
	11 - Intralock	-	-	-	4	4	4	2	2	2	2	2	2	2	2	2	2	32
	12 - Conc./Conc.	-	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	26
	13 - Control Concrete	-	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	26

[1] Epoxy allowed to become tacky prior to placing fresh concrete. For the cement-based bonding agents, fresh concrete was immediately placed after applying bonding agent.
[2] Fresh concrete immediately placed after applying bonding agent.
[3] For the cement-based bonding agents, a 1 h delay occurred between placing the bonding agent and casting fresh concrete for two of the four specimens cast. See [2] above for application procedures of the remaining specimens.
[4] For slump and mix proportions, see Table 2.

TABLE 6
NUMBER OF COMPOSITE SPECIMENS PREPARED AND TESTED UNDER VARIOUS CURING CONDITIONS

Test	Product Identification	23°C, 50% rh							Total Number of Specimens
		Vertically Cast Specimens Age (Days)			Horizontally Cast Specimens Age (Days)				
		3	7	28	3	7	28	28 days + 11 months at 23°C and 100% rh	
CRDC C89-64 Shear Strength	1 - Acryl Set	3	3	3	3	3	3	3	21
	2 - Anvil Bond	3	3	3	3	3	3	3	21
	3 - Sikadur 32	3	3	3	3	3	3	3	21
	4 - Nitobond	3	3	3	3	3	3	3	21
	5 - Monobond	3	3	3	3	3	3	3	21
	6 - Cappar 19	3	3	3	3	3	3	3	21
	7 - ST 433	3	3	3	3	3	3	3	21
	8 - Sikacem	3	3	3	3	3	3	3	21
	9 - Neat cement	3	3	3	3	3	3	3	21
	10 - Q stick 103	3	3	3	3	3	3	3	21
	11 - Intralock	3	3	3	3	3	3	3	21
	12 - Conc./Conc.	3	3	3	3	3	3	3	21
	13 - Control Concrete	3	3	3	3	3	3	3	21

TABLE 7

NUMBER OF REPAIR MATERIAL SPECIMENS PREPARED AND TESTED UNDER VARIOUS CURING CONDITIONS

Test	Product Identification	Age: 14 days
ASTM C666 Procedure A Freeze/Thaw Resistance	1 - Acryl Set	3
	2 - Anvil Bond	3
	3 - Sikadur 32	3
	4 - Nitobond	3
	5 - Monobond	3
	6 - Cappar 19	3
	7 - ST 433	3
	8 - Sikacem	3
	9 - Neat Cement	3
	10 - Q Stick 103	3
	11 - Intralock	3
	12 - Conc./Conc.	3
	13 - Control Concrete	3

TABLE 8

TACK, OPEN AND HARD TIMES OF EPOXIES TESTED AT 10°C, 23°C AND 32°C

Material	10°C				23°C			32°C		
	Wet Film Thickness (mm)	Tack Time (h)	Open Time (h)	Hard Time (h)	Tack Time (h)	Open Time (h)	Hard Time (h)	Tack Time (h)	Open Time (h)	Hard Time (h)
(2) Anvil Bond	0.25	6.25	10.25	12.25	2.75	3.90	5.25	3.0	3.45	3.45
(3) Sikadur 32	0.25	8.25	12.5	14.5	2.75	3.9	4.0	2.4	2.5	2.5
(4) Nitobond	0.25	50	>67	>74	23.5	25.0	>30.0	15.25	19.25	>25.25
(5) Monobond	0.25	5.25	9.75	>24	4.15	4.95	5.15	2.2	3.2	4.2
(6) Cappar 19	0.25	6.0	9.5	37.5	2.0	2.8	3.2	2.1	2.4	2.5
(7) ST 433	0.25	7.5	14.5	24.5	3.2	5.1	7.5	2.4	3.3	4.3
(10) Q Stick	0.25	14.5	25.5	>50	4.8	6.0	7.2	4.3	5.0	6.8

Note: 1) Tack, open and hard times of epoxy were also determined using a wet film thickness of 0.45 mm. There was generally very little difference in results when compared with the 0.25 mm film thickness (ie, slight reduction in times).

2) Definition of:

Tack Time: The period between mixing the two components of an epoxy, and the material becoming tacky

Open Time: The period between when the material becomes tacky and when it hardens

Hard Time : The stage where a reacting liquid epoxy has hardened

TABLE 9

COMPRESSIVE STRENGTH - ASTM C109

Material	COMPRESSIVE STRENGTH (MPa)					
	Cured 23°C and 100% rh Age (Days)			Cured 23°C and 50% rh Age (Days)		
	1	7	28	1	7	28
(1) Acryl Set	5.9	24.1	32.8	7.0	27.7	41.6
(2) Anvil Bond	73.6	75.6	74.7	72.5	74.7	74.3
(3) Sikadur 32 Hi Mod	57.1	63.8	64.4	41.5	64.5	67.7
(4) Nitobond	2.7	9.2	12.0	2.3	7.1	12.0
(5) Monobond	28.0	35.9	41.2	17.0	35.8	40.4
(6) Cappar 19	64.7	67.7	70.1	58.7	67.9	68.9
(7) ST 433	80.6	85.3	88.0	69.9	85.0	88.1
(8) Sikacem	16.4	45.0	54.9	12.9	35.0	35.6
(9) Neat Cement	19.4	48.4	60.5	19.7	47.0	49.8
(10) Q Stick 103	76.8	81.1	84.4	76.1	79.3	83.8
(11) Intralock	16.3	45.8	51.2	18.0	49.7	59.7
(13) Control Concrete	18.7	24.7	32.5	-	-	-

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TABLE 10

COMPRESSIVE STRENGTH - ASTM C 109

Product Identification		28-Day Compressive Strength (MPa) Cured under Various Conditions		28-Day Compressive Strength as a % of Control Concrete	
		23°C 100% rh	23°C 50% rh	23°C 100% rh	23°C 50% rh
(1)	Acryl Set	32.8	41.6	101	128
(2)	Anvil Bond	74.7	74.3	229	228
(3)	Sikadur 32	64.4	67.0	198	208
(4)	Nitobond	12.0	12.0	37	37
(5)	Monobond	41.2	40.4	126	124
(6)	Cappar 19	70.1	68.9	215	212
(7)	ST 433	88.0	88.1	270	271
(8)	Sikacem	54.9	35.6	169	109
(9)	Neat Cement	60.5	49.8	186	153
(10)	Q Stick 103	84.4	83.8	259	257
(11)	Intralock	51.2	59.7	157	184
(12)	Conc./Conc.	-	-	-	-
(13)	Control Conc.	32.5	-	100	-

TABLE 11

BOND STRENGTH - ASTM C 882
3-DAY TEST RESULTS

Material	23°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /2/			23°C 25 MPa, 150 mm Slump /1/			23°C 25 MPa, 240 mm Slump Super Plasticized Concrete /1/			10°C 25 MPa, 75-100 mm Slump /1/			30°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /3/		
	Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load	Failure Mode	
		C	B		C	B		C	B		C	B		C	B		C	B		C	B
(1) Acryl Set	–	–	–	13.3	20	80	13.4	25	75	14.2	25	75	7.9	50	50	14.4	30	70	8.6	25	75
(2) Anvil Bond	14.6	25	75	16.0	30	70	–	–	–	–	–	–	5.9	25	75	3.0	–	100	-	-	-
(3) Sikadur 32	8.2	–	100	11.0	–	100	–	–	–	–	–	–	6.8	100	–	13.0	90	10	-	-	-
(4) Nitobond	5.1	–	100	0.8	–	100	–	–	–	–	–	–	1.7	–	100	5.4	5	95	-	-	-
(5) Monobond	5.9	25	75	1.6	–	100	–	–	–	–	–	–	2.0	20	80	9.7	25	75	-	-	-
(6) Cappar 19	14.2	75	25	2.7	–	100	–	–	–	–	–	–	6.9	50	50	13.1	75	25	-	-	-
(7) ST 433	9.4	25	75	3.5	–	100	–	–	–	–	–	–	6.5	90	10	13.5	60	40	-	-	-
(8) Sikacem	–	–	–	12.8	50	50	–	–	–	–	–	–	6.3	50	50	14.1	50	50	8.9	50	50
(9) Neat Cement	–	–	–	13.6	–	100	–	–	–	–	–	–	8.4	50	50	15.3	100	–	10.7	100	-
(10) Q Stick	2.5	–	100	1.0	–	100	–	–	–	–	–	–	4.7	5	95	8.5	5	95	-	-	-
(11) Intralock	–	–	–	14.5	–	100	–	–	–	–	–	–	7.1	75	25	14.2	95	5	9.0	50	50
(12) Conc./Conc.	–	–	–	10.4	–	100	–	–	–	–	–	–	5.3	10	90	11.1	15	85	-	-	-
(13) Control Concrete	–	–	–	20.2	–	–	24.1	–	–	25.9	–	–	12.3	–	–	24.2	–	–	-	-	-

/1/ Epoxy allowed to tack prior to placing concrete. Cement bonding agent with and without latex placed on hardened concrete and fresh concrete immediately placed
/2/ Bonding agent placed on hardened concrete and fresh concrete immediately placed
/3/ Cement bonding agent with and without latex placed on hardened concrete and fresh concrete placed 1h later

Note: C - refers to failure within the concrete
B - refers to adhesive failure

TABLE 12

BOND STRENGTH - ASTM C 882
7-DAY TEST RESULTS

Material	23°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /2/			23°C 25 MPa, 150 mm SlumP /1/			23°C 25 MPa, 240 mm Slump Super Plasticized Concrete /1/			10°C 25 MPa, 75-100 mm Slump /1/			30°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /3/		
	Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load	Failure Mode	
		C	B		C	B		C	B		C	B		C	B		C	B		C	B
(1) Acryl Set	--	--	--	14.5	20	80	13.4	25	75	14.2	25	75	10.6	60	40	15.7	90	10	9.6	40	60
(2) Anvil Bond	16.9	25	75	19.0	25	75	14.8	25	75	10.6	25	75	9.0	25	75	5.3	25	75	--	--	--
(3) Sikadur 32	10.0	--	100	13.1	--	100	14.0	100	--	14.6	50	50	11.4	95	5	14.6	90	10	--	--	--
(4) Nitobond	8.2	--	100	0.6	--	100	6.1	--	--	8.2	25	75	7.8	10	90	7.8	10	90	--	--	--
(5) Monobond	7.2	25	75	3.0	--	100	13.6	25	75	9.7	25	75	3.5	5	95	11.3	40	60	--	--	--
(6) Cappar 19	18.5	25	75	8.3	--	100	15.7	100	--	15.2	50	50	11.5	90	10	15.5	90	10	--	--	--
(7) ST 433	11.9	25	75	6.4	25	75	14.1	25	75	13.2	25	75	10.8	95	5	15.4	90	10	--	--	--
(8) Sikacem	--	--	--	14.5	20	80	14.0	100	--	15.3	25	75	9.3	70	30	14.5	50	50	10.4	75	25
(9) Neat Cement	--	--	--	16.6	100	--	14.4	100	--	15.4	100	--	11.6	90	10	17.2	100	--	11.8	100	--
(10) Q Stick	5.7	--	100	1.4	--	100	5.0	--	--	7.2	--	100	7.4	10	90	10.6	10	90	--	--	--
(11) Intralock	--	--	--	16.3	60	40	13.1	100	--	15.0	100	--	7.8	100	--	15.5	100	--	9.7	100	--
(12) Conc./Conc.	--	--	--	12.9	20	80	12.7	20	80	16.2	75	25	6.1	10	90	11.2	30	70	--	--	--
(13) Control Concrete	--	--	--	24.5	--	--	24.1	--	--	25.9	--	--	17.7	-	-	27.4	--	--	--		--

/1/ Epoxy allowed to tack prior to placing concrete. Cement bonding agent with and without latex placed on hardened concrete and fresh concrete immediately placed
/2/ Bonding agent placed on hardened concrete and fresh concrete immediately placed
/3/ Cement bonding agent with and without latex placed on hardened concrete and fresh concrete placed 1 h later

Note: C - refers to failure within the concrete
B - refers to adhesive failure

TABLE 13

BOND STRENGTH -ASTM C 882
28 -DAY TEST RESULTS

Material	23°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /2/			23°C 25 MPa, 150 mm Slump /1/			23°C 25 MPa, 240 mm Slump Super Plasticized Concrete /1/			10°C 25 MPa, 75-100 mm Slump /1/			30°C 25 MPa, 75-100 mm Slump /1/			23°C 25 MPa, 75-100 mm Slump /3/		
	Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load (MPa)	Failure Mode (%)		Failure Load	Failure Mode	
		C	B		C	B		C	B		C	B		C	B		C	B		C	B
(1) Acryl Set	-	-	-	15.8	50	50	14.5	100	-	16.5	95	5	13.5	60	40	17.2	100	-	10.4	75	25
(2) Anvil Bond	20.0	50	50	20.5	30	70	16.0	95	5	12.6	30	70	12.6	25	75	4.5	10	90	-	-	-
(3) Sikadur 32	13.3	-	100	15.8	20	80	14.8	100	-	16.8	95	5	15.4	100	-	15.5	75	25	-	-	-
(4) Nitobond	11.6	-	100	1.0	-	100	10.0	20	80	12.2	50	50	14.7	25	75	9.1	50	50	-	-	-
(5) Monobond	8.5	10	90	8.0	-	100	16.1	95	5	12.7	25	75	11.1	25	75	12.9	40	50	-	-	-
(6) Cappar 19	21.4	100	-	8.1	10	90	17.8	100	-	17.9	90	10	15.1	100	-	18.7	95	5	-	-	-
(7) ST 433	13.7	90	10	10.1	20	80	14.6	90	10	13.5	40	60	12.8	90	10	16.8	95	5	-	-	-
(8) Sikacem	-	-	-	16.9	50	50	14.8	100	-	16.3	100	-	10.7	75	25	16.4	95	5	12.2	100	-
(9) Neat Cement	-	-	-	17.5	100	-	15.5	100	-	16.2	100	-	14.1	80	20	17.3	100	-	10.4	100	-
(10) Q Stick	16.4	100	-	3.9	-	100	13.1	100	-	16.0	100	-	18.3	100	-	11.3	10	90	-	-	-
(11) Intralock	-	-	-	18.1	100	-	14.7	100	-	17.1	100	-	10.0	50	50	16.7	100	-	9.9	50	50
(12) Conc./Conc.	-	-	-	13.9	25	75	13.7	25	75	17.0	75	25	8.3	10	90	12.1	25	75	-	-	-
(13) Control Concrete	-	-	-	26.2	-	-	25.2	-	-	26.2	-	-	21.3	-	-	31.2	-	-	-	-	-

/1/ Epoxy allowed to tack prior to placing concrete. Cement bonding agent with and without latex placed on hardened concrete and fresh concrete immediately placed
/2/ Bonding agent placed on hardened concrete and fresh concrete immediately placed.
/3/ Cement bonding agent with and without latex placed on hardened concrete and fresh concrete placed 1 h later

Note: C - refers to failure within the concrete
B - refers to adhesive failure

TABLE 14

BOND STRENGTH - ASTM C 882
28 -DAY TEST RESULTS EXPRESSED AS A PERCENT OF THE CONTROL CONCRETE *

Material	23°C 75-100 mm Slump /1/	23°C 75-100 mm Slump /2/	23°C 150 mm Slump /1/	23°C 240 mm Slump /1/	10°C 75-100 mm Slump /1/	30°C 75-100 mm Slump /1/	23°C 75-100 mm Slump /3/
(1) Acryl Set	-	60	55	63	52	66	40
(2) Anvil Bond	76	78	61	48	48	17	-
(3) Sikadur 32	51	60	56	64	59	59	-
(4) Nitobond		4	38	48	56	35	-
(5) Monobond	44	31	61	48	42	49	-
(6) Cappar 19	32	31	68	68	58	71	-
(7) ST 433	82	39	56	51	49	64	-
(8) Sikacem	53	65	56	62	41	63	47
(9) Neat Cement	-	67	59	62	54	66	40
(10) Q Stick	-	15	50	62	69	43	-
(11) Intralock	-	69	56	65	39	64	38
(12) Conc./Conc.	63	53	52	65	32	46	-

*Control: All tests have been compared to control concrete cured 28 days at 23 °C and 100 % rh.

/1/ Epoxy allowed to tack prior to placing concrete. Cement bonding agent with and without latex placed on hardened concrete and fresh concrete immediately placed.
/2/ Bonding agent placed on hardened concrete and fresh concrete immediately placed.
/3/ Cement bonding agent with and without latex placed on hardened concrete and fresh concrete placed 1 h later.

TABLE 15

BOND STRENGTH - ASTM C 882
EFFECT OF TIME DELAY BETWEEN APPLYING
BONDING AGENT AND PLACEMENT OF FRESH CONCRETE

Material	23°C, 75 -100 mm Slump Concrete				
	Bonding Agent Applied and Fresh Concrete Placed 45 Minutes Later Bond Strength (MPa) Age (Days)			Bonding Agent Applied and Fresh Concrete Immediately Placed Bond Strength (MPa) Age (Days)	
	3	7	28	7	28
(1) Acryl Set	8.6	9.6	10.4	13.4	14.5
(8) Sikacem	8.9	10.4	12.2	14.0	14.8
(9) Neat Cement	10.7	11.8	10.4	14.4	15.5
(11) Intralock	9.0	9.7	9.9	13.1	14.7

TABLE 16

BOND STRENGTH - ASTM C 882
EFFECT OF PLACING FRESH CONCRETE
IMMEDIATELY AFTER APPLYING EPOXY BONDING AGENT

Material	Bond Strength (MPa) 28 Days - 23°C	
	Epoxy Allowed to Tack Prior to Placing Concrete	Epoxy Placed on Hardened Concrete and Fresh Concrete Immediately Placed
(2) Anvil Bond	20.0	20.5
(3) Sikadur 32	13.3	15.8
(4) Nitobond	11.6	1.0
(5) Monobond	8.5	8.0
(6) Cappar 19	21.4	8.0
(7) ST 433	13.7	10.1
(10) Q Stick 103	16.4	3.9

TABLE 17

SHEAR STRENGTH OF COMPOSITE SPECIMENS - CRDC - C 89 - 64 MODIFIED

Material	3-Day Shear Strength (MPa) Cured at 23°C and 50% rh						7-Day Shear Strength (MPa) Cured at 23°C and 50% rh					
	Vertically Cast Slabs	Failure Mode (%)		Horizontally Cast Slabs	Failure Mode (%)		Vertically Cast Slabs	Failure Mode (%)		Horizontally Cast Slabs	Failure Mode (%)	
		C	B		C	B		C	B		C	B
(1) Acryl Set	1.5	--	100	2.5	70	30	2.4	--	100	4.2	95	5
(2) Anvil Bond	1.0	--	100	1.3	5	95	0.9	--	100	1.5	5	95
(3) Sikadur 32	2.5	30	70	2.0	30	70	2.2	5	95	2.7	5	95
(4) Nitobond	1.4	--	100	1.5	5	95	1.4	--	100	1.8	5	95
(5) Monobond	2.2	10	90	2.5	20	80	2.9	90	10	3.3	90	10
(6) Cappar 19	2.8	65	35	2.9	95	5	3.2	80	20	3.2	30	70
(7) ST 433	2.5	90	10	2.9	95	5	3.2	90	10	3.3	95	5
(8) Sikacem	1.7	60	40	2.7	100	--	2.4	60	40	4.1	100	--
(9) Neat Cement	2.9	25	75	3.3	50	50	4.0	95	5	3.6	80	20
(10) Q Slick	1.0	--	100	0.9	--	100	1.5	--	100	1.7	5	95
(11) Intralock	2.6	70	30	3.1	95	5	3.4	65	35	4.1	95	5
(12) Conc./Conc.	0.9	10	90	2.6	45	55	1.7	5	95	2.8	15	85
(13) Control Concrete	2.5	--	--	2.8	--	--	3.2	--	--	3.4	--	--

Note: C - refers to failure within the concrete
B - refers to adhesive failure

TABLE 18

SHEAR STRENGTH OF COMPOSITE SPECIMENS - CRDC - C 89 - 64 MODIFIED

Material	28-Day Shear Strength (MPa) Cured at 23°C and 50% rh									28-Day Shear Strength Expressed as a % of Control *		
	Vertically Cast Slabs	Failure Mode (%)		Horizontally Cast Slabs	Failure Mode (%)		After 300 Freeze/Thaw Cycles	Failure Mode (%)		Vertically Cast Slabs	Horizontally Cast Slabs	After 300 Freeze/Thaw Cycles
		C	B		C	B		C	B			
(1) Acryl Set	3.6	85	15	4.4	100	-	4.9	100	-	78	96	106
(2) Anvil Bond	1.6	-	100	1.8	-	100	0.6	-	100	35	39	13
(3) Sikadur 32	3.0	15	85	2.9	10	90	1.0	-	100	65	63	22
(4) Nitobond	1.9	-	100	1.7	5	95	1.3	5	95	41	37	28
(5) Monobond	3.1	15	85	3.1	5	95	3.6	20	80	67	67	78
(6) Cappar 19	2.9	25	75	3.1	70	30	5.0	50	50	63	68	109
(7) ST 433	3.8	80	20	4.1	90	10	3.8	95	5	82	89	83
(8) Sikacem	4.5	100	-	3.0	65	35	4.6	100	-	98	65	100
(9) Neat Cement	4.5	100	-	4.2	95	5	6.1	-	100	98	91	132
(10) Q Stick	4.2	75	25	4.4	90	10	4.3	25	75	91	96	93
(11) Intralock	4.7	95	5	4.9	95	5	5.9	75	25	102	107	128
(12) Conc./Conc.	4.3	95	5	4.0	95	5	4.1	100	-	93	87	89
(13) Control Concrete	4.6	-	-	4.6	-	-	5.9	-	-	100	100	128

*Control: All tests have been compared to control concrete cured at 23°C and 50 % rh for 28 days.

Note: C - refers to failure within the concrete
B - refers to adhesive failure

TABLE 19

SHEAR STRENGTH OF COMPOSITE SPECIMENS PRIOR TO AND AFTER 300 FREEZE/THAW CYCLES

Material	Shear Strength (MPa) 28 -Day Results	Failure Mode % Failure		Durability Factor 300 Cycles Freeze/Thaw	Shear Strength (MPa) After Freeze/Thaw	Failure Mode % Failure	
		Concrete	Bond			Concrete	Bond
(1) Acryl Set	4.4	100	-	98.9 /1/	4.9	100	-
(2) Anvil Bond	1.8	-	100	99.8 /1/2/	0.6	-	100
(3) Sikadur 32	2.9	10	90	94.6 /1/	1.0	-	100
(4) Nitobond	1.7	10	90	101.3 /1/	1.3	5	95
(5) Monobond	3.1	10	90	101.5 /1/	3.6	20	80
(6) Cappar 19	3.1	30	70	98.8 /1/	5.0	50	50
(7) ST 433	4.1	90	10	99.1 /1/	3.8	95	5
(8) Sikacem	3.0	65	35	97.7 /1/	4.6	100	-
(9) Neat Cement	4.2	95	5	97.3 /1/	6.1	-	100
(10) Q Stick 103	4.4	90	10	98.3 /1/	4.3	25	75
(11) Intralock	4.9	90	10	95.2 /1/	5.9	75	25
(12) Conc./Conc.	4.0	90	10	98.1 /1/	4.1	100	-
(13) Control Conc.	4.6	-	-	97.7 /1/	5.9	100	-

/1/ Light scaling

/2/ Separation at joint noted approx. 3/4 lenght of prism

TABLE 20

EVALUATION OF BONDING AGENTS FOR REPAIR OF CONCRETE STRUCTURES
FREEZE/THAW TEST RESULTS - ASTM C666 PROCEDURE A

Material	Number of Cycles at end of Freeze/Thaw	Dynamic Modulus		% Eo	Pulse Velocity				Weight Change %	Durability Factor 300 Cycles
					Length		Across Bond			
		Eo	Ef		Vo	Vf	Vo	Vf		
(1) Acryl Set	300	36.71	36.28	98.9	4640	4450	4620	4620	-0.02	98.9 /1/
(2) Anvil Bond	300	36.06	35.64	98.8	4620	4420	4420	4420	-0.215	98.8 /1/2/
(3) Sikadur 32	300	37.30	35.31	94.6	4520	4430	4550	4360	-1.01	94.6 /1/
(4) Nitobond	310	36.83	37.41	101.6	4450	4520	4480	4420	-0.12	101.3 /1/
(5) Monobond	310	39.62	40.23	101.5	4300	4360	4390	4230	-0.05	101.5 /1/
(6) Cappar 19	300	37.40	36.96	98.9	4520	4450	4420	4490	-0.09	98.8 /1/
(7) ST433	310	38.61	38.16	98.9	4390	4420	4400	4550	-0.11	99.1 /1/
(8) Sikacem	300	35.77	34.93	97.7	4620	4490	4620	4550	-0.26	97.7 /1/
(9) Neat Cement	300	40.07	39.02	97.3	4640	4470	4620	4420	-0.16	97.3 /1/
(10) Q-Stick 103	310	37.31	36.60	98.1	4420	4450	4480	4300	-0.07	98.3 /1/
(11) Intralock	300	39.96	38.02	95.2	4620	4450	4420	4420	-0.30	95.2 /1/
(12) Conc./Conc	300	38.55	37.81	98.1	4640	4450	4620	4490	-0.09	98.1 /1/
(13) Control Concrete	300	36.68	35.81	97.7	4570	4520	4360	4360	-0.41	97.7 /1/

/1/ Light scaling of concrete.
/2/ One of the three specimens broke in 2 pieces along bond line at 240 cycles.

Note: Eo = Original dynamic modulus
Ef = Final dynamic modulus
Vo = Original pulse velocity
Vf = Final pulse velocity

TABLE 21

SUMMARY OF THE PERFORMANCE /1/ OF COMPOSITE AND REPAIR MATERIAL SPECIMENS TESTED UNDER DIFFERENT CONDITIONS

Material	28-Day Compressive Strength		28-Day Bond Strength							28-Day Shear Strength		
	23°C Wet	23°C Dry	23°C 75-100 mm Slump /2/	23°C 75-100 mm Slump /3/	23°C 150 mm Slump /2/	23°C 240 mm Slump /2/	10°C 75-100 mm Slump /2/	30°C 75-100 mm Slump /2/	23°C 75-100 mm Slump /4/	Vertically Cast Slabs	Horizontally Cast Slabs	After 300 Freeze/Thaw Cycles
(1) Acryl Set	P	P	-	P	P	P	P	P	Q	P	P	P
(2) Anvil Bond	P	P	P	P	P	Q	Q	Q	-	Q	Q	Q
(3) Sikadur 32	P	P	P	P	P	P	P	P	-	P	P	Q
(4) Nitobond	Q	Q	Q	Q	Q	Q	P	Q	-	Q	Q	Q
(5) Monobond	P	P	Q	Q	P	Q	Q	Q	-	P	P	P
(6) Cappar 19	P	P	P	Q	P	P	P	P	-	P	P	P
(7) ST 433	P	P	P	Q	P	P	Q	P	-	P	P	P
(8) Sikacem	P	P	-	P	P	P	Q	P	Q	P	P	P
(9) Neat Cement	P	P	-	P	P	P	P	P	Q	P	P	P
(10) Q Stick	P	P	P	Q	P	P	P	Q	-	P	P	P
(11) Intralock	P	P	-	P	P	P	Q	P	Q	P	P	P
(12) Conc./Conc.	P	P	-	P	P	P	Q	Q	-	P	P	P
(13) Control	P	P	P	P	P	P	P	P	P	P	P	P

Note: Blank (-) indicates product not tested - Q = questionable - P = pass

/1/ Materials were questionable (identified as 'Q') if their compressive strength was less than 80% of the control or their bond or shear strength was less than 50% of the control
/2/ Epoxy allowed to tack prior to placing concrete. Cement bonding agent with or without latex placed on hardened concrete and fresh concrete immediately placed
/3/ Bonding agent placed on hardened concrete and fresh concrete immediately placed
/4/ Cement bonding agent with or without latex placed on hardened concrete and fresh concrete placed 1 h later

APPENDIX A

TEST METHODS FOR PHYSICAL PROPERTIES OF BONDING AGENTS

TEST	METHOD AND APPLICATION CONDITIONS
VISCOSITY	Measured with a Brookfield RVT viscometer at temperatures of 10°, 23° and 32°C. All materials were conditioned and tested at the required temperature.
TACK, OPEN, HARD TIMES	Determined using a Beck Koller dry time recorder at 10°, 23° and 32°C. All equipment and materials were conditioned and tested at the required temperature.
COMPRESSIVE STRENGTH	Determined in accordance with ASTM C 109 and tested at 23°C, 50% and 100% relative humidity.
FLEXURAL STRENGTH	Determined in accordance with ASTM C 78 modified. Tests carried out at 14 days.
COEFFICIENT OF THERMAL EXPANSION	Determined in accordance with ASTM C 531 modified. Tests carried out under two different temperature ranges: (a) 23° to - 25°C (b) 23° to +100°C The change in length at the various temperatures was used to calculate the coefficient of thermal expansion.

APPENDIX B

TEST METHODS FOR COMPOSITE SPECIMENS

TEST	METHOD AND APPLICATION CONDITIONS
SHEAR STRENGTH	Determined in accordance with CRDC C 89 - 64 modified. Test specimens were cut from composite slabs 406 mm x 406 mm x 150 mm (See Figure 2).
BOND STRENGTH	Determined in accordance with ASTM C 882 modified. Specimens were made, conditioned and tested at 10°, 23° and 30°C. A 25-MPa concrete having the following slump was used to cast the top half of the composite specimens: (a) 23°C - 75 - 100 mm slump - 150 mm slump - 240 mm slump (b) 10°C - 75 - 100 mm slump (c) 30°C - 75 - 100 mm slump

APPENDIX C

BOND STRENGTH OF BONDING AGENTS TESTED UNDER DIFFERENT CONDITIONS AT 28 DAYS

FIGURE	PRODUCT	MATERIAL
C 1	1	Acryl Set
C 2	2	Anvil Bond
C 3	3	Sikadur 32
C 4	4	Nitobond
C 5	5	Monobond
C 6	6	Cappar 19
C 7	7	ST 433
C 8	8	Sikacem
C 9	9	Neat Cement
C 10	10	Q Stick 103
C 11	11	Intralock
C 12	12	Concrete/Concrete
C 13	13	Control Concrete

178912-RD
BART 7 DISK

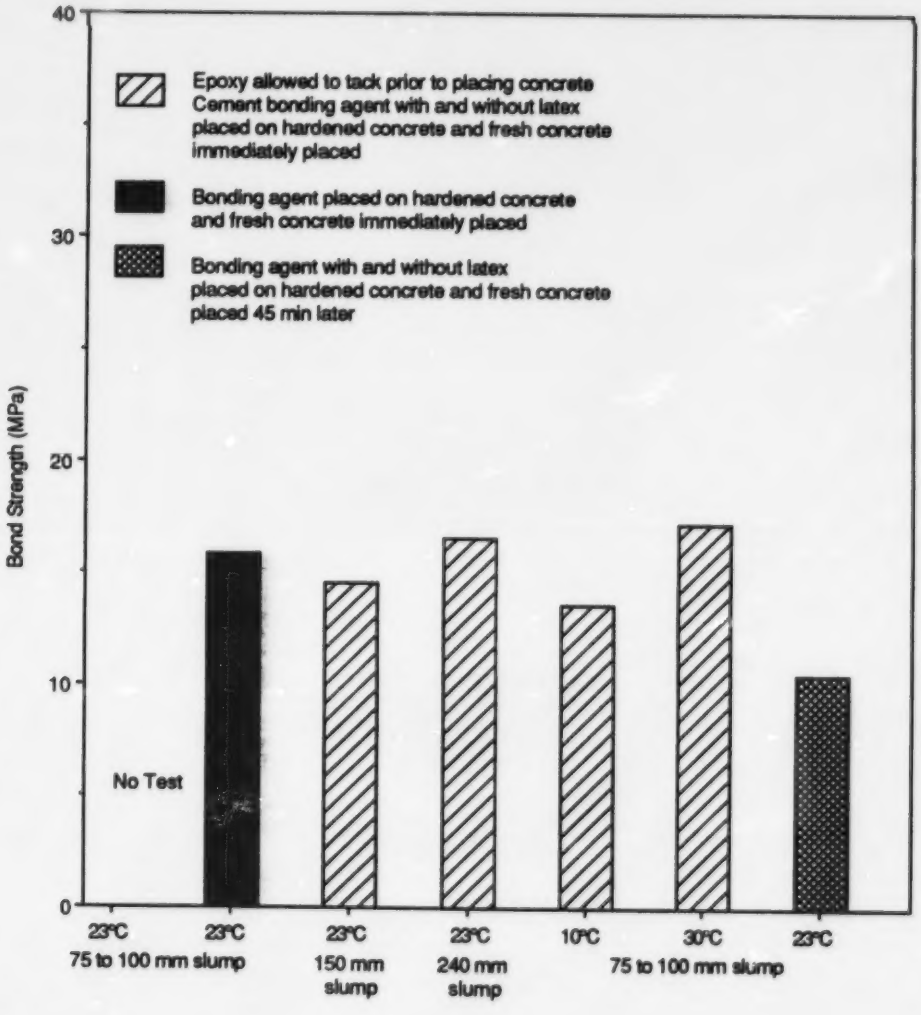

FIGURE C1

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 1

178402-RD
JA 9 DISK

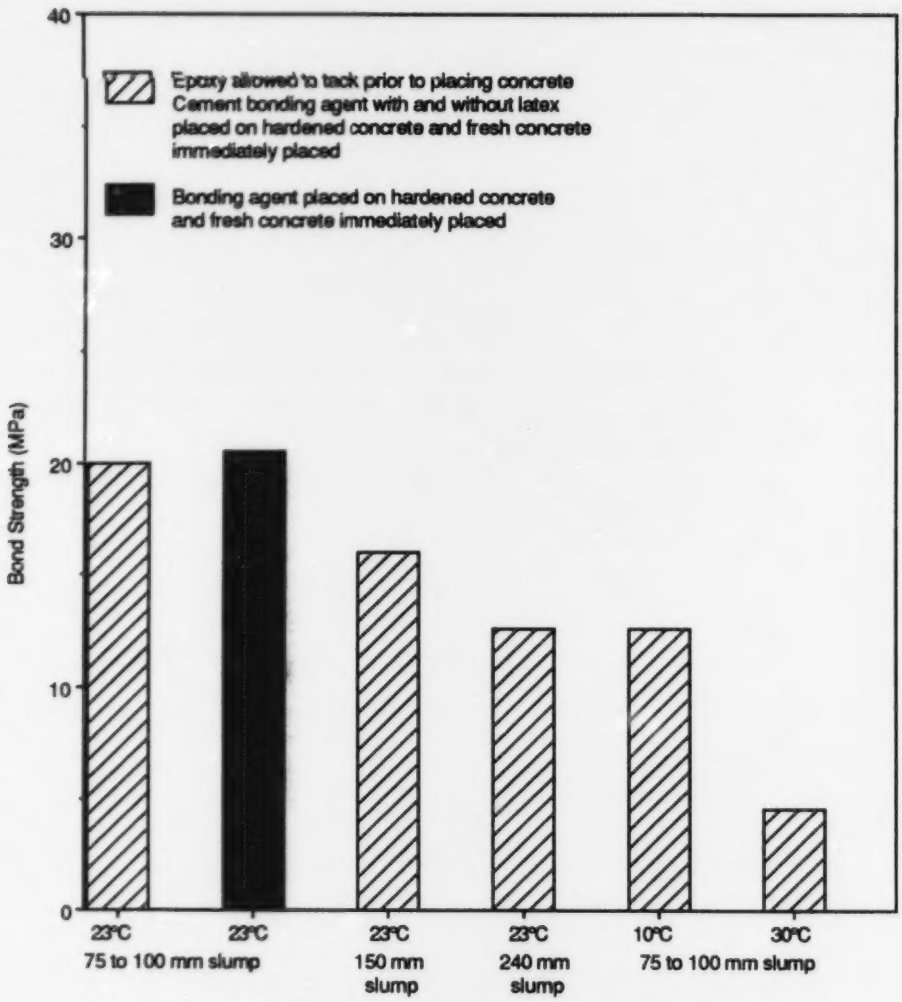

FIGURE C2

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 2

178403-RD
JA 9 DISK

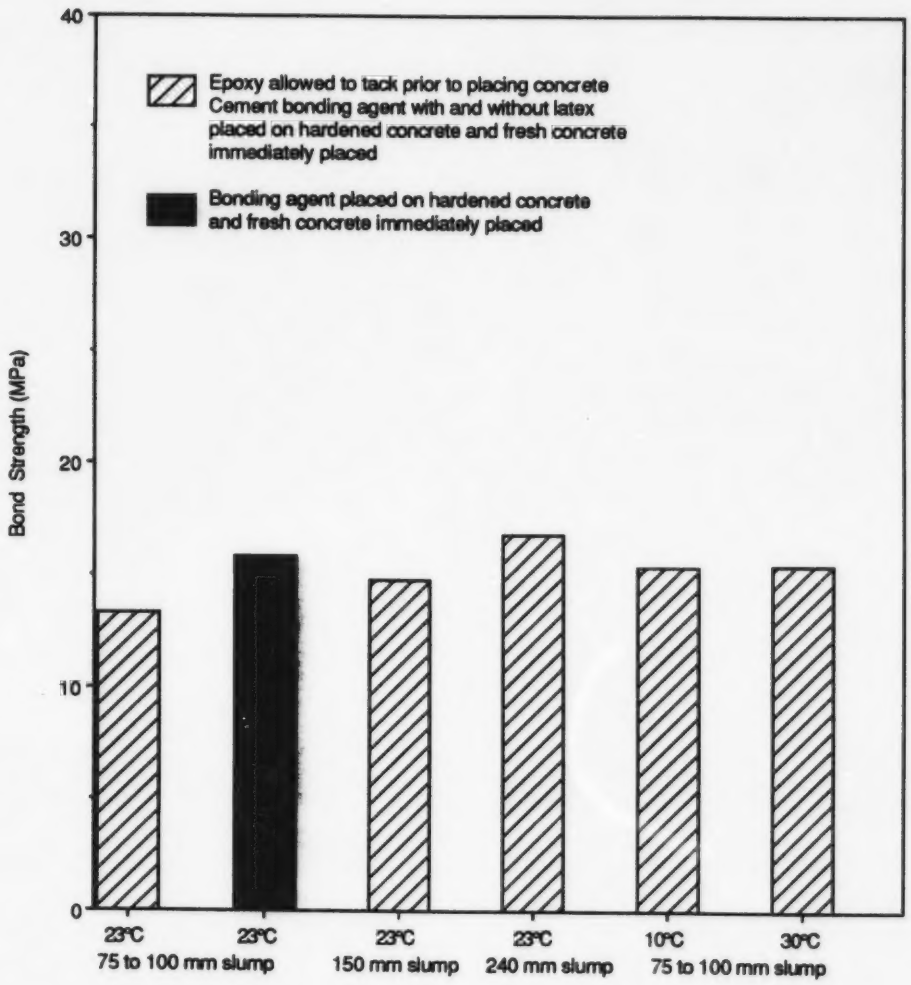

FIGURE C3

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES
ASTM C 882 - BOND STRENGTH
28-DAY TEST RESULTS
PRODUCT 3

178404-RD
JA 9 DISK

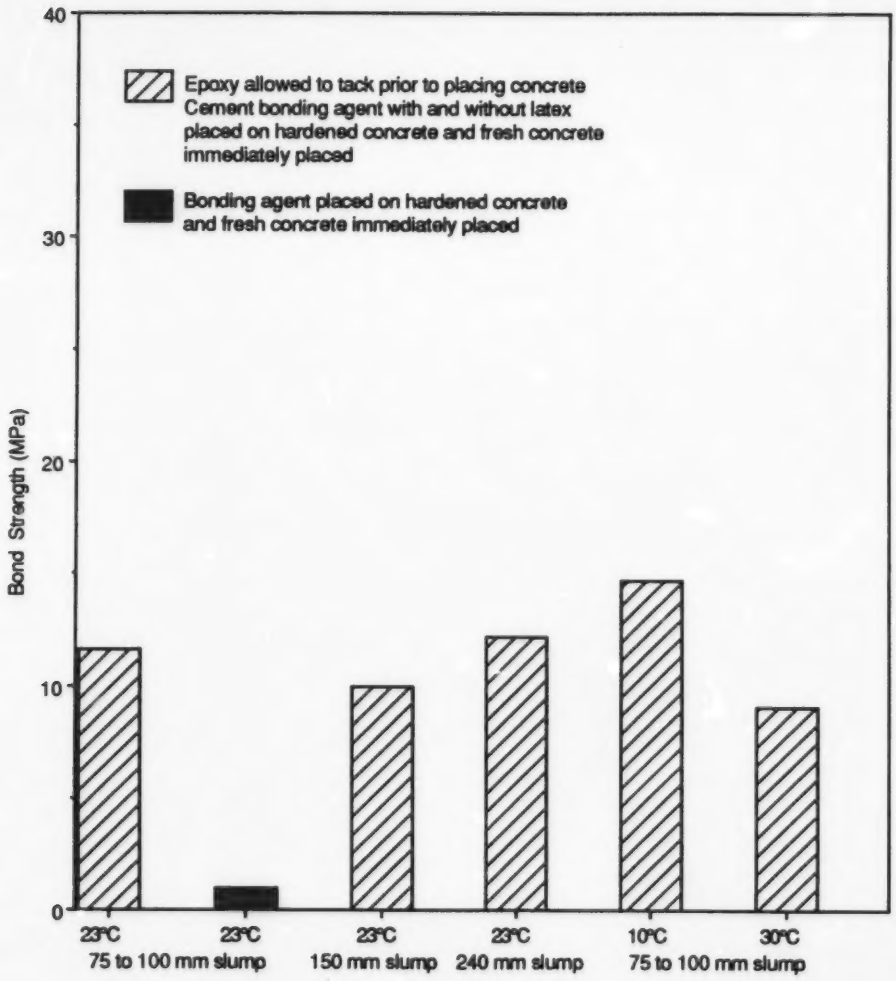

FIGURE C4

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES
ASTM C 882 - BOND STRENGTH
28-DAY TEST RESULTS
PRODUCT 4

178405-RD
JA 9 DISK

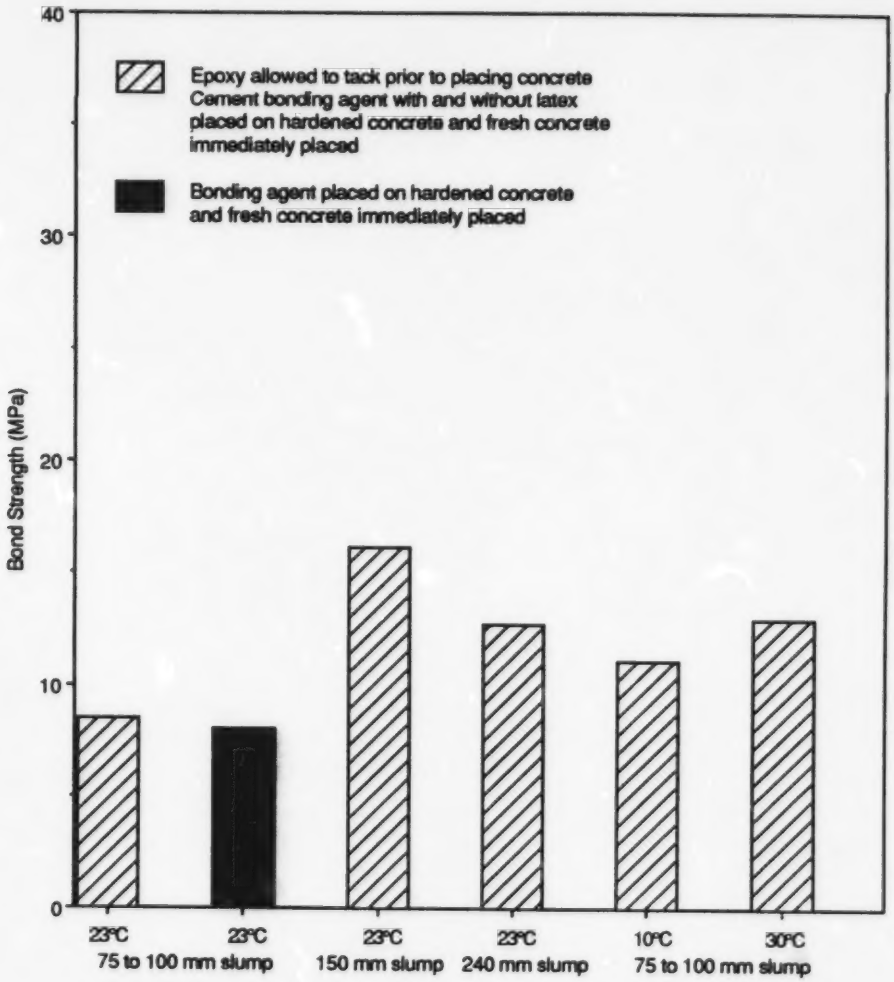

FIGURE C5

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 5

178406-RD

JA 9 DISK

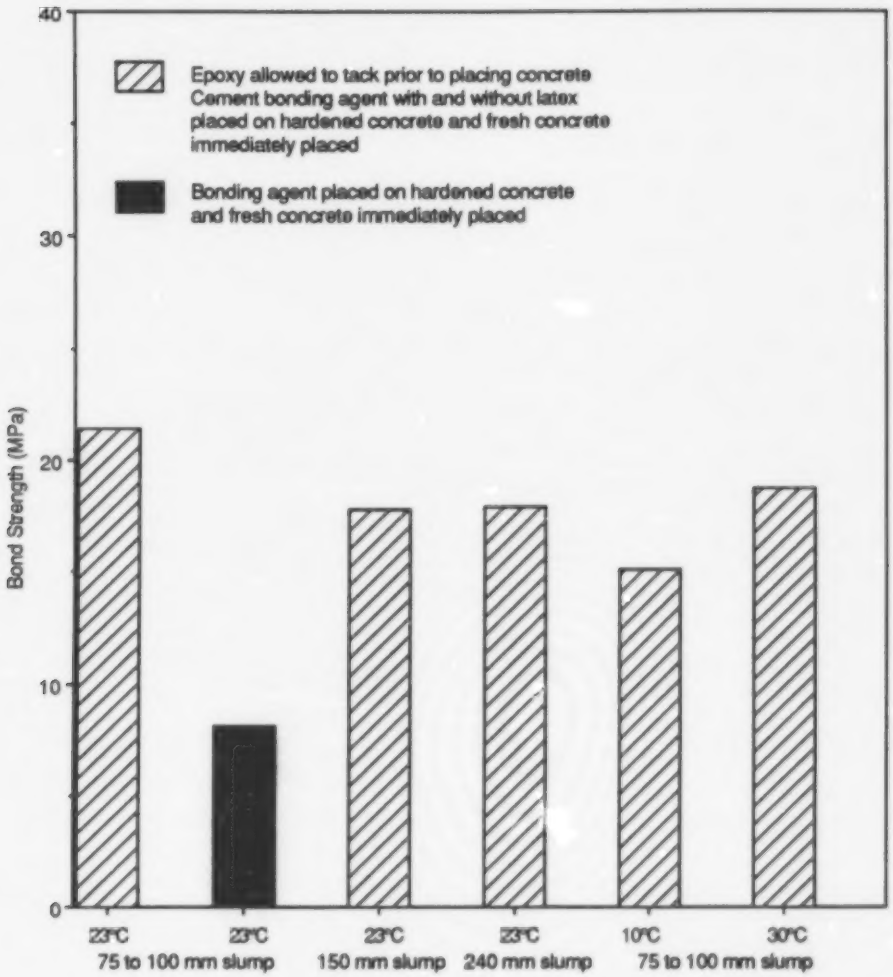

FIGURE C6

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 6

178407-RD
JA 9 DISK

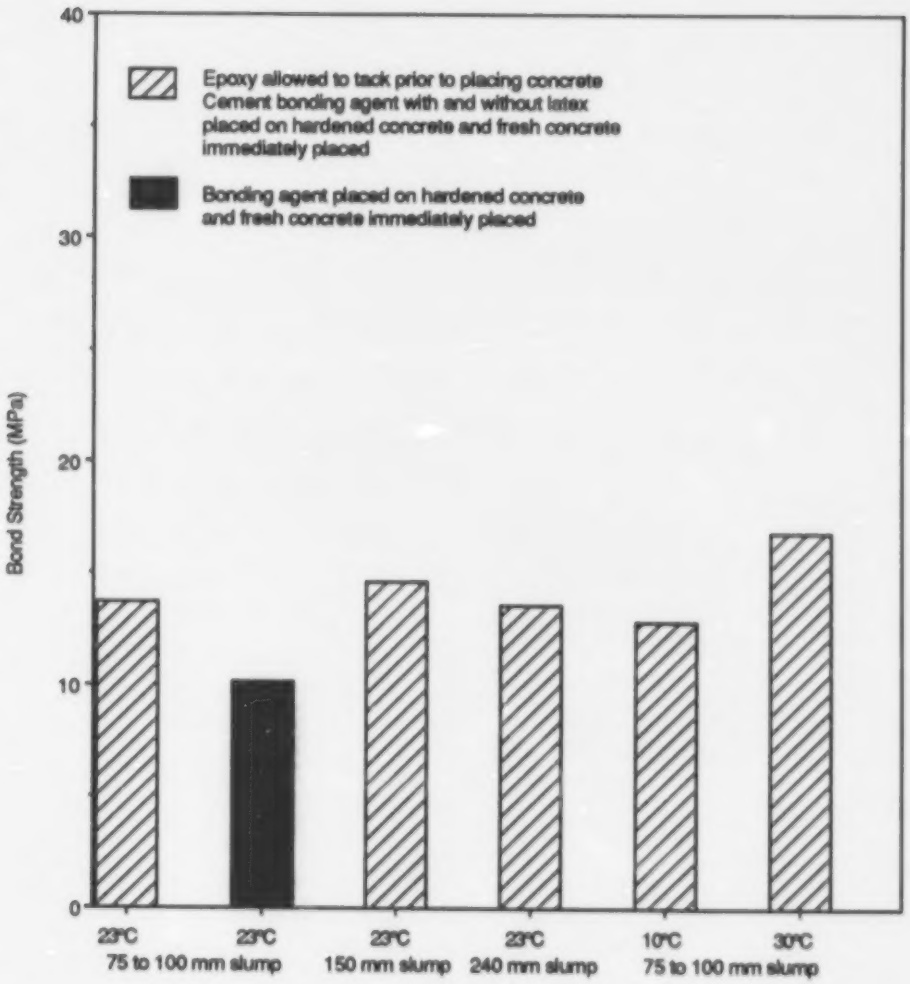

FIGURE C7

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 7

178408-RD
JA 9 DISK

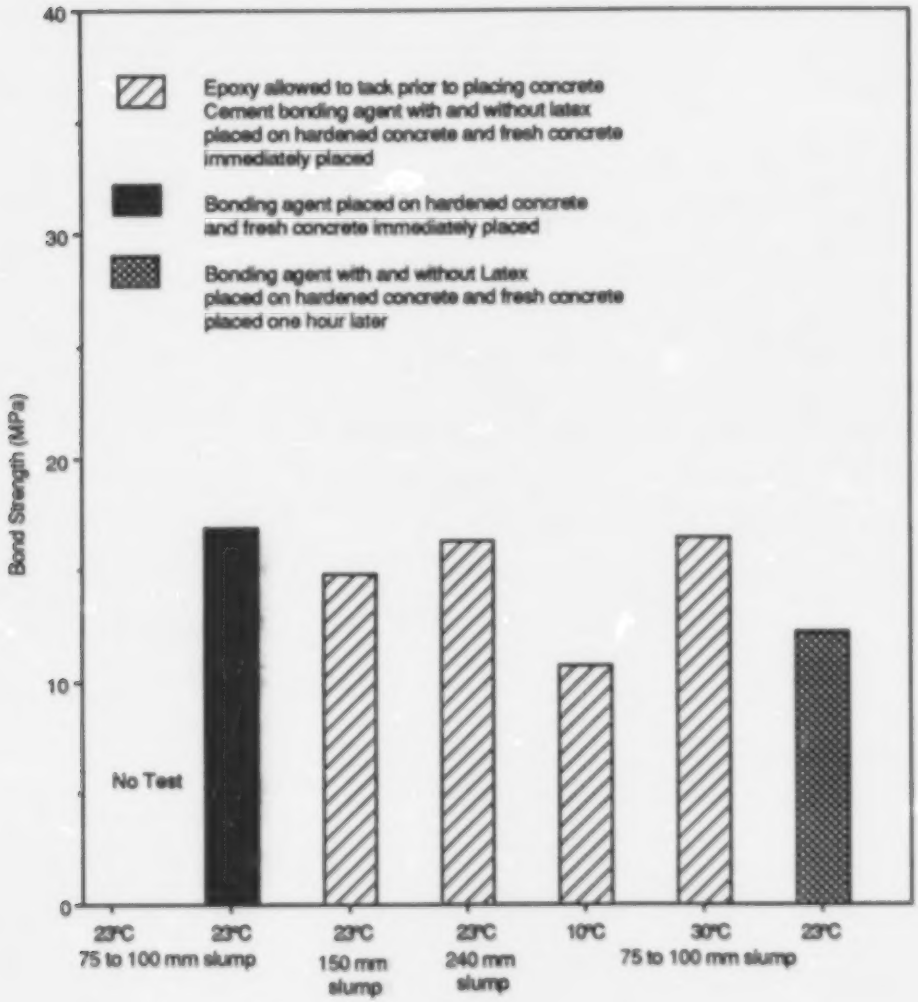

FIGURE C8

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 8

178409-RD
JA 9 DISK

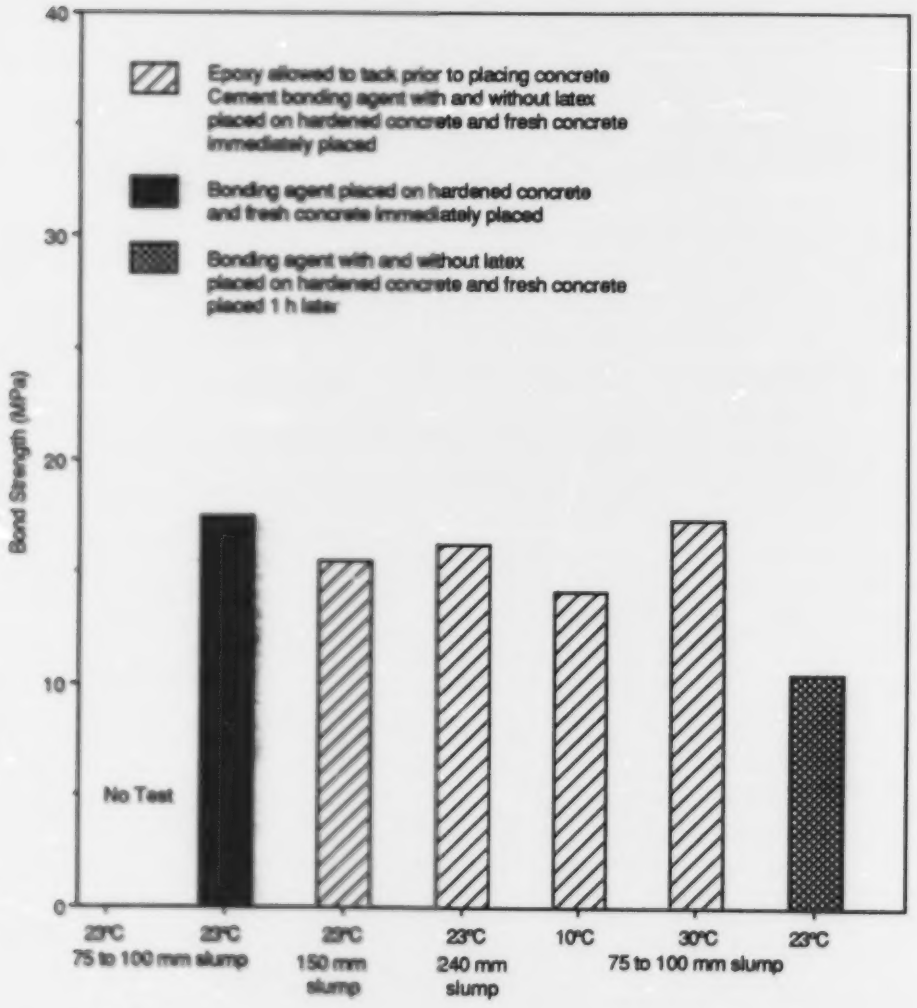

FIGURE C9

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 9

178410-RD
JA 9 DISK

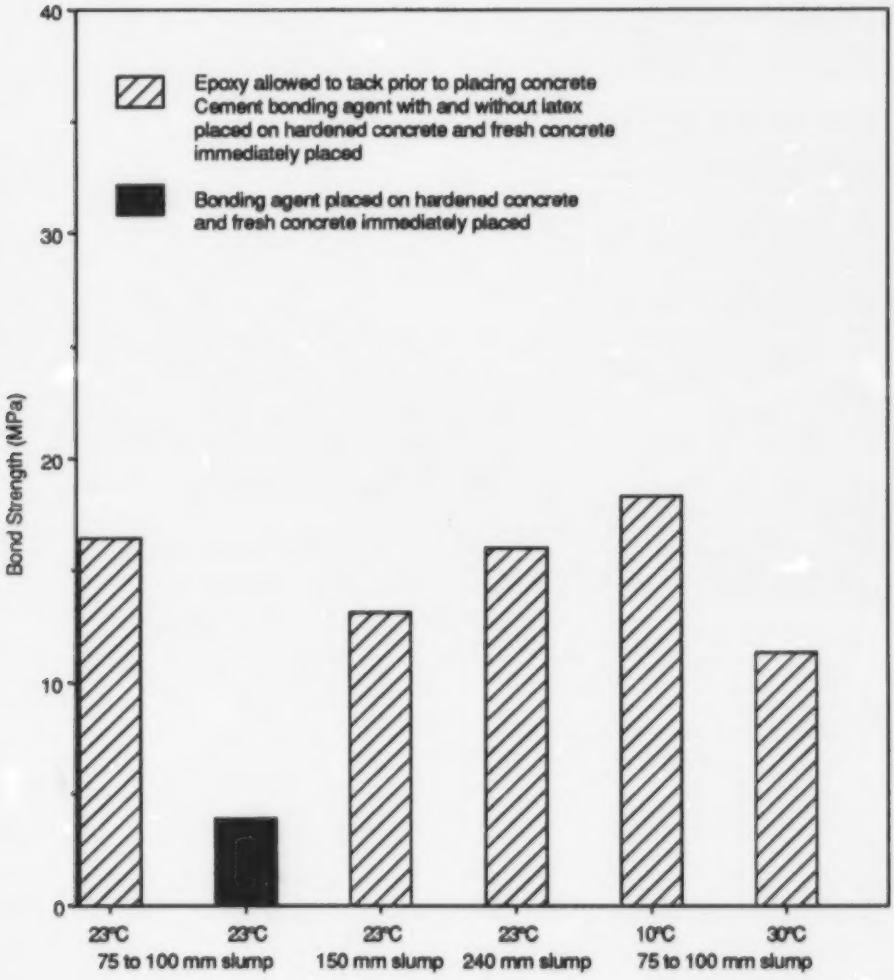

FIGURE C10

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 10

178411-RD
JA 9 DISK

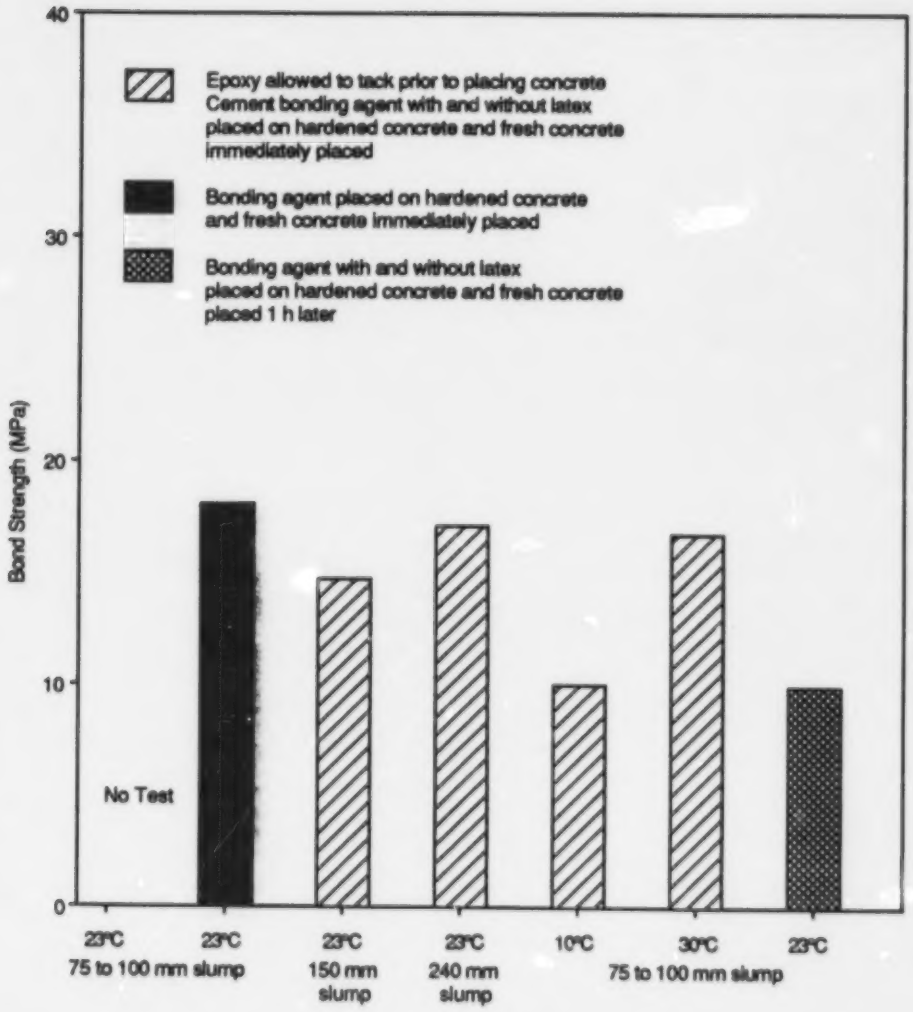

FIGURE C11

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 11

178412-RD
JA 9DIBK

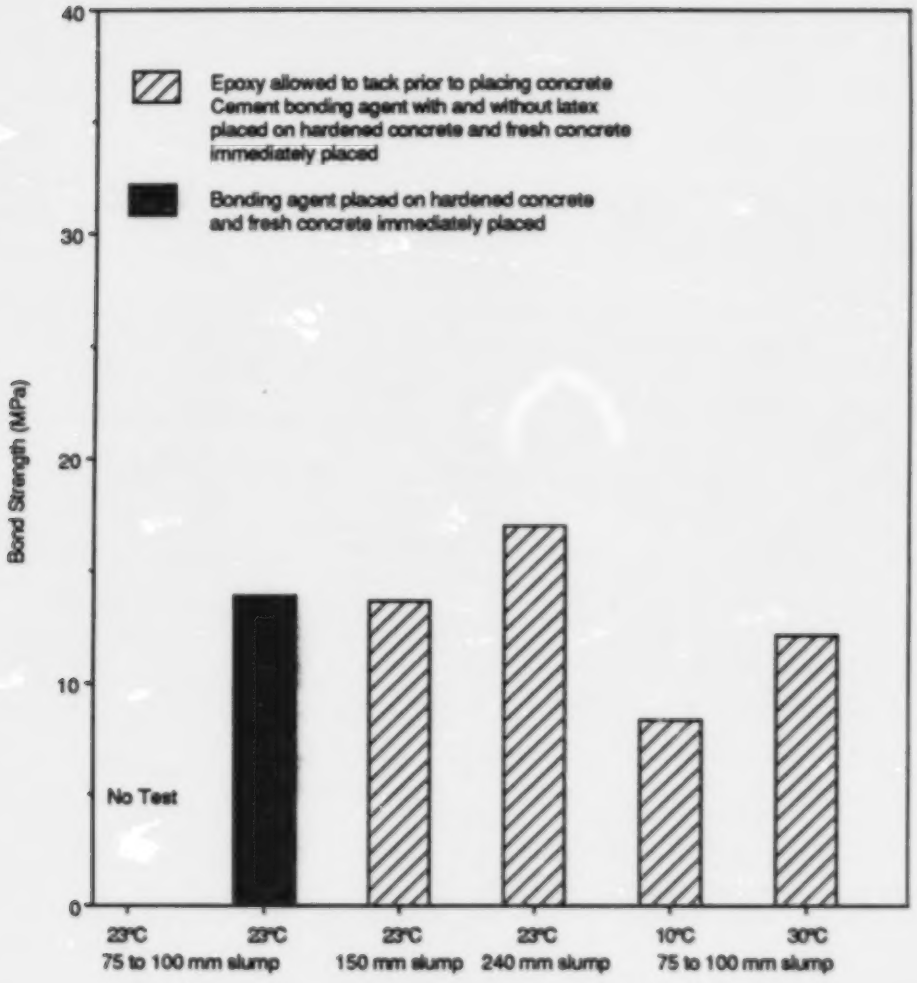

FIGURE C12

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES ASTM C 882 - BOND STRENGTH 28-DAY TEST RESULTS PRODUCT 12

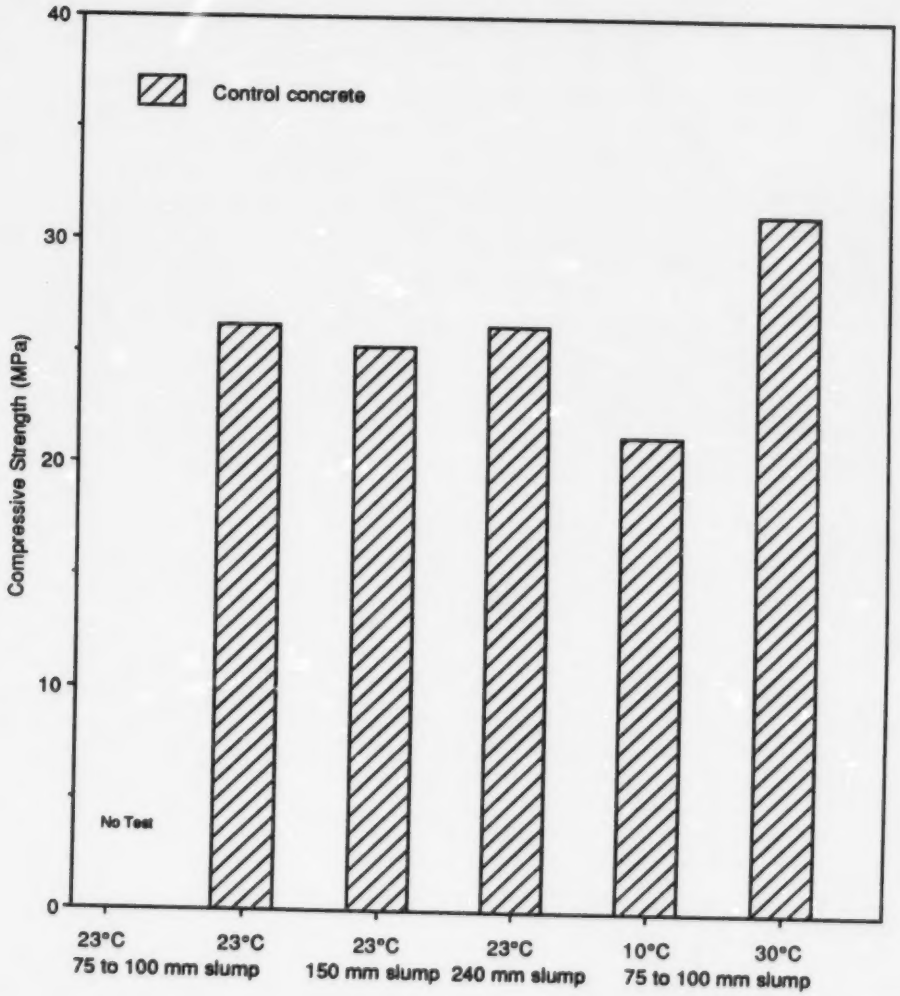

FIGURE C13

EVALUATION OF BONDING AGENTS FOR USE IN REPAIRING CONCRETE STRUCTURES
ASTM C 882 - COMPRESSIVE STRENGTH OF CONTROL CONCRETE
28-DAY TEST RESULTS
PRODUCT 13

178415-RD
JA 9 DISK

APPENDIX D

SHEAR STRENGTH OF BONDING AGENTS TESTS AT DIFFERENT AGES

FIGURE	PRODUCT	MATERIAL
D 1	1	Acryl Set
D 2	2	Anvil Bond
D 3	3	Sikadur 32
D 4	4	Nitobond
D 5	5	Monobond
D 6	6	Cappar 19
D 7	7	ST 433
D 8	8	Sikacem
D 9	9	Neat Cement
D 10	10	Q Stick 103
D 11	11	Intralock
D 12	12	Concrete/Concrete
D 13	13	Control Concrete

178911-RD
BART 7 DISK

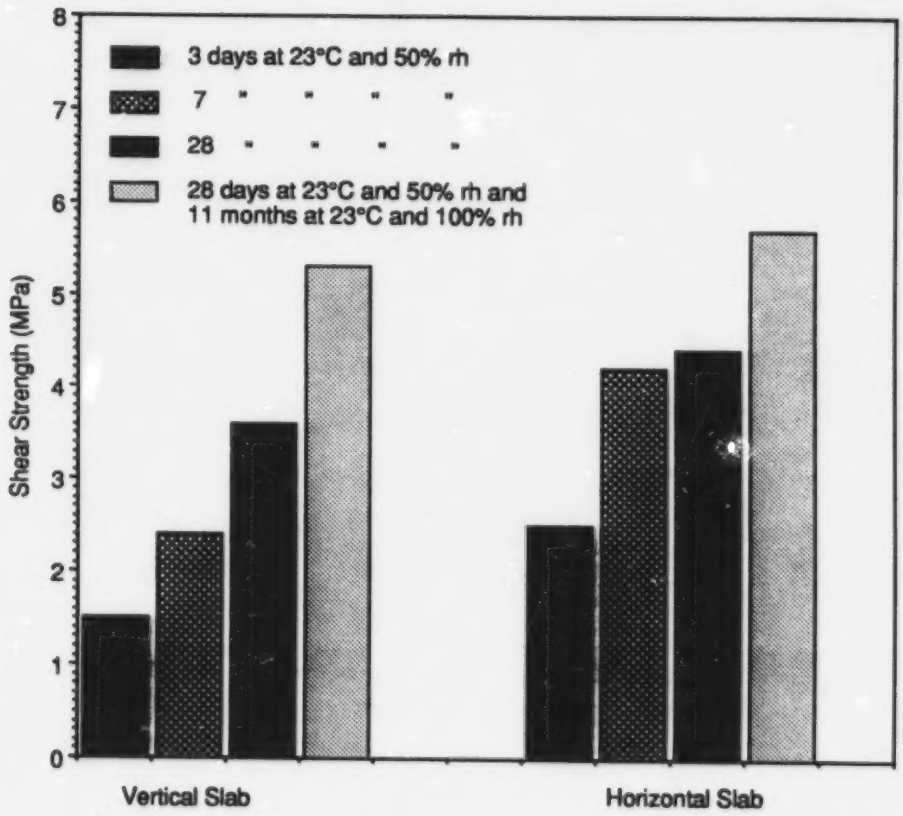

FIGURE D1

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 1

178455-RD
JA 9 DISK

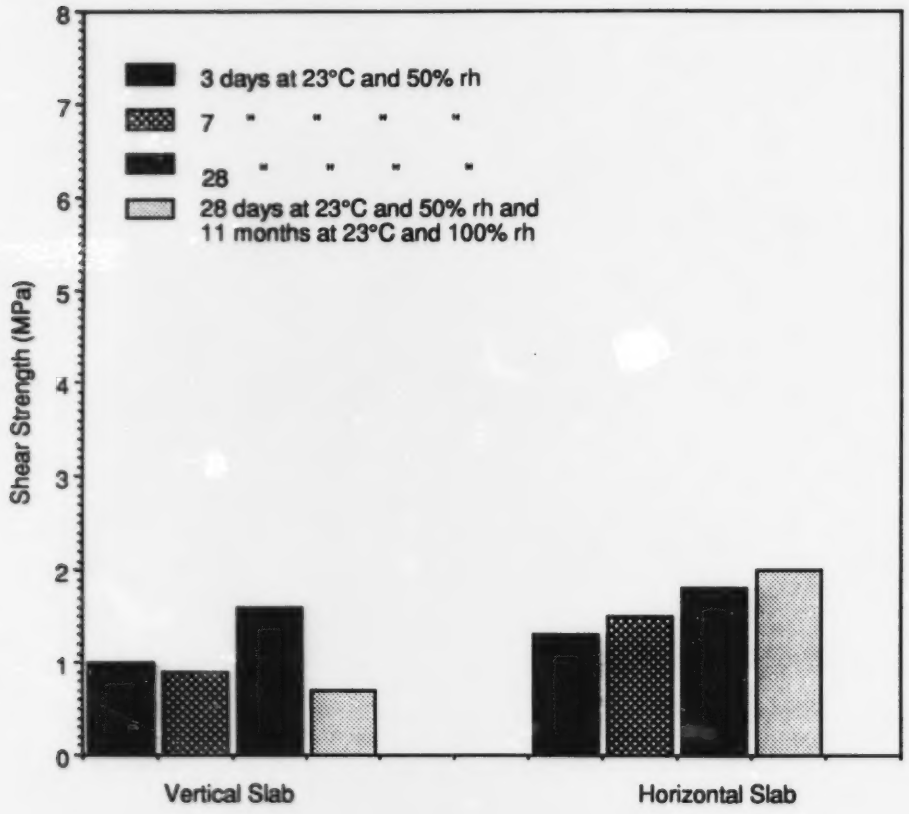

FIGURE D2

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 2

178454-RD
JA 9 DISK

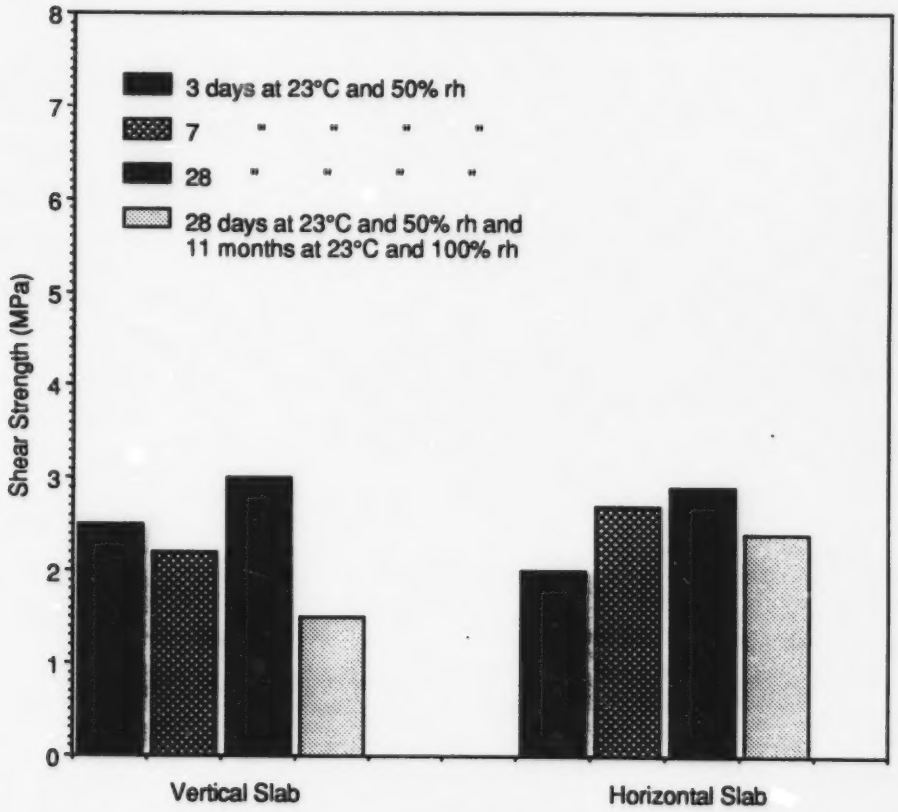

FIGURE D3

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 3

178453-RD
JA 8 DISK

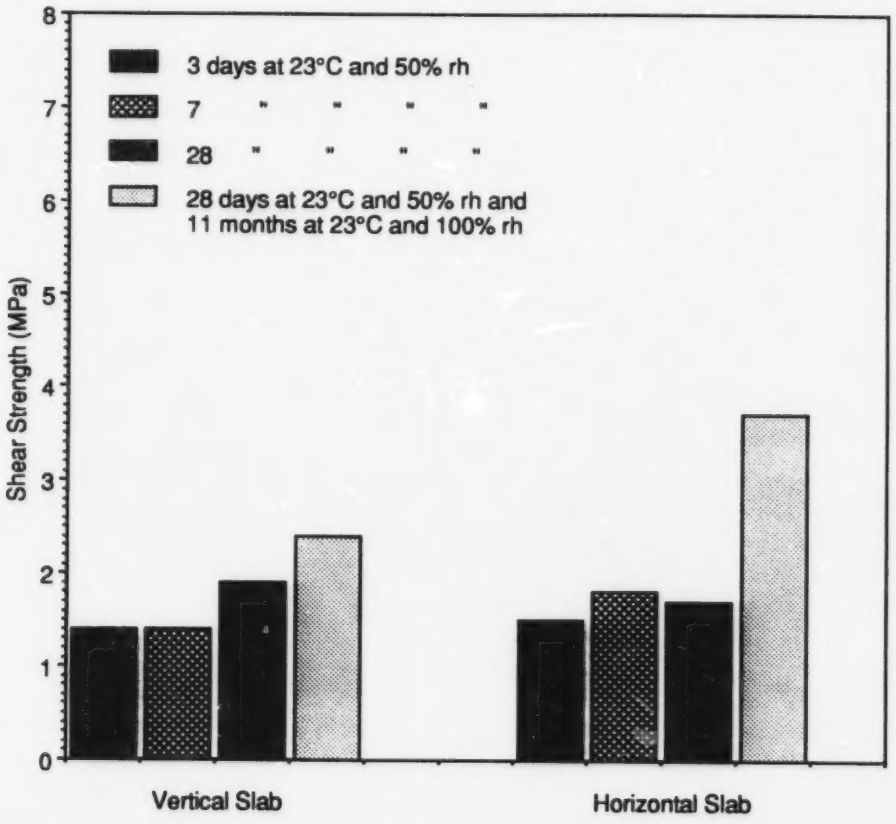

FIGURE D4

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 4

178452-RD
JA 9 DISk

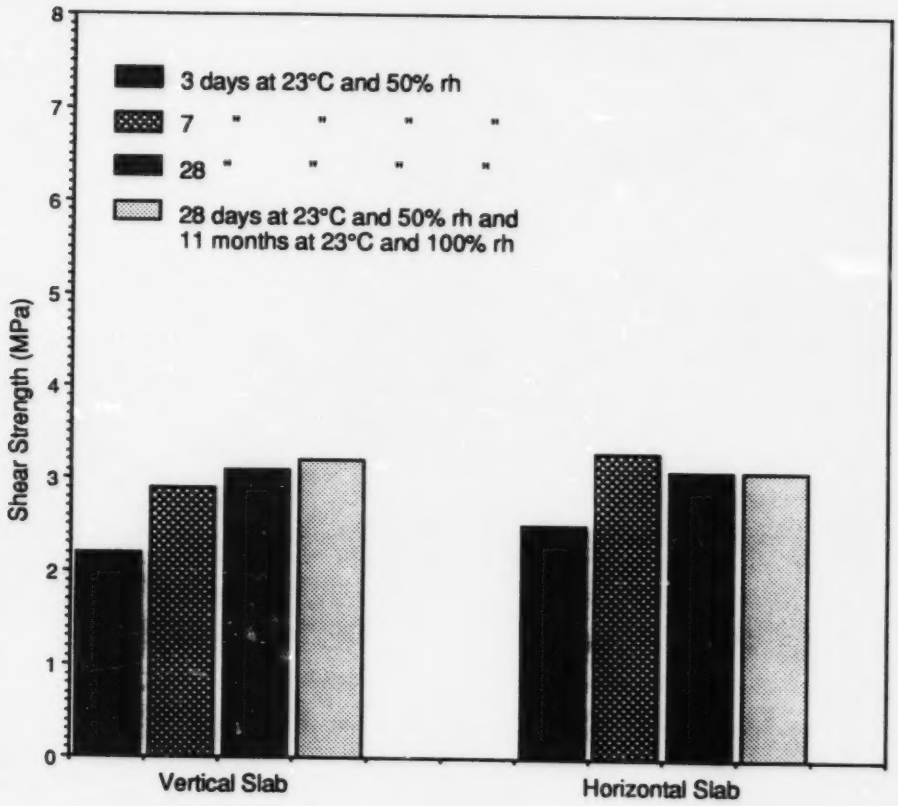

FIGURE D5

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 5

178451-RD
JA 9 DISK

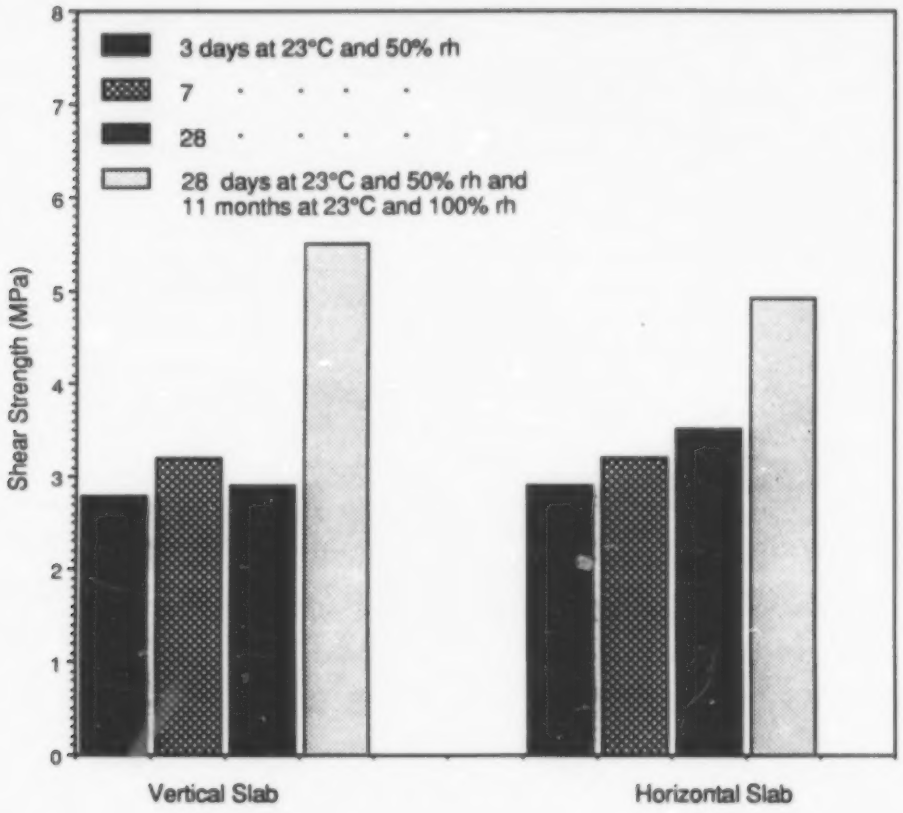

FIGURE D6

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 6

178450-RD
JA 9 DISK

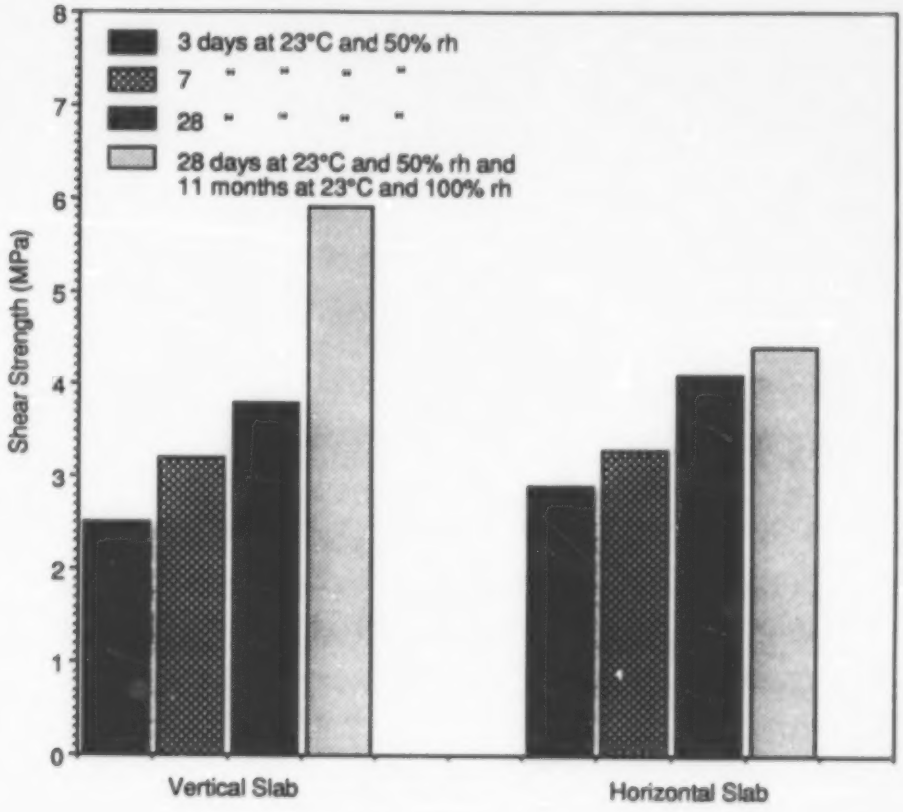

FIGURE D7

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 7

178449-RD
JA 9 DISK

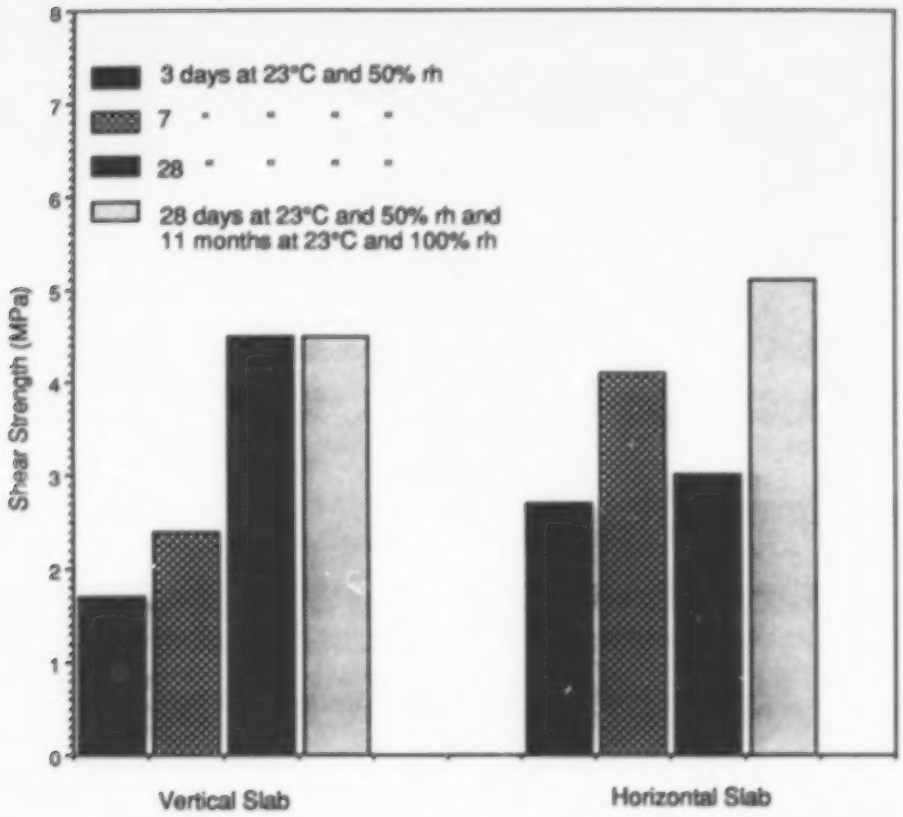

FIGURE D8

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 8

178448-RD
JA 9 DISK

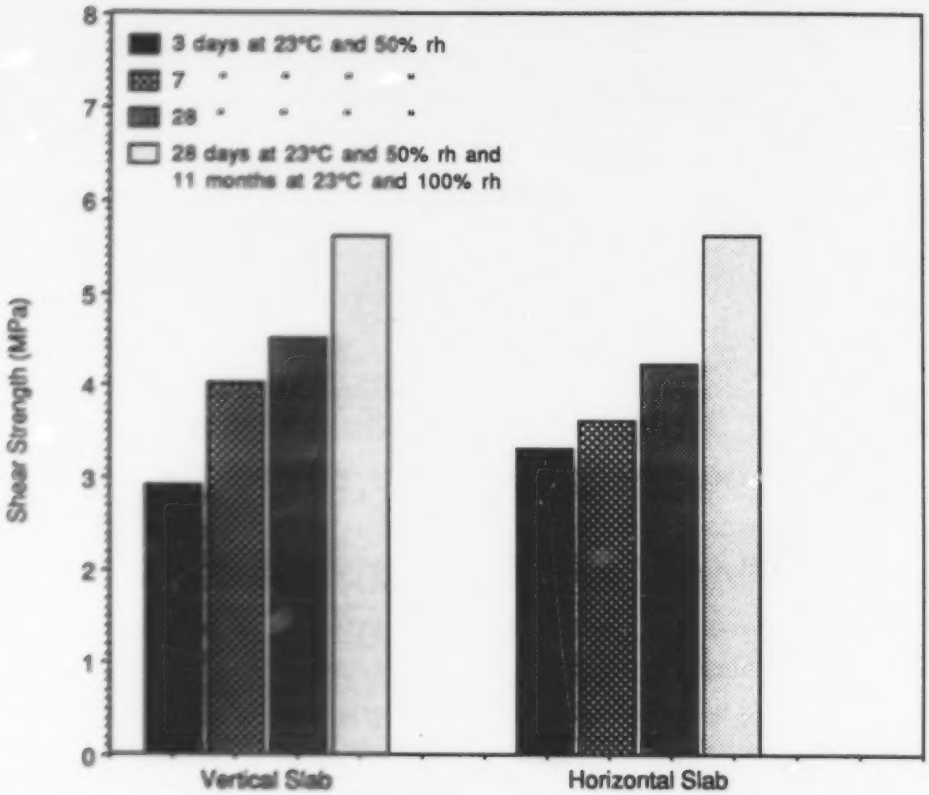

FIGURE D9

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 9

178447 RD
DEAN-G1

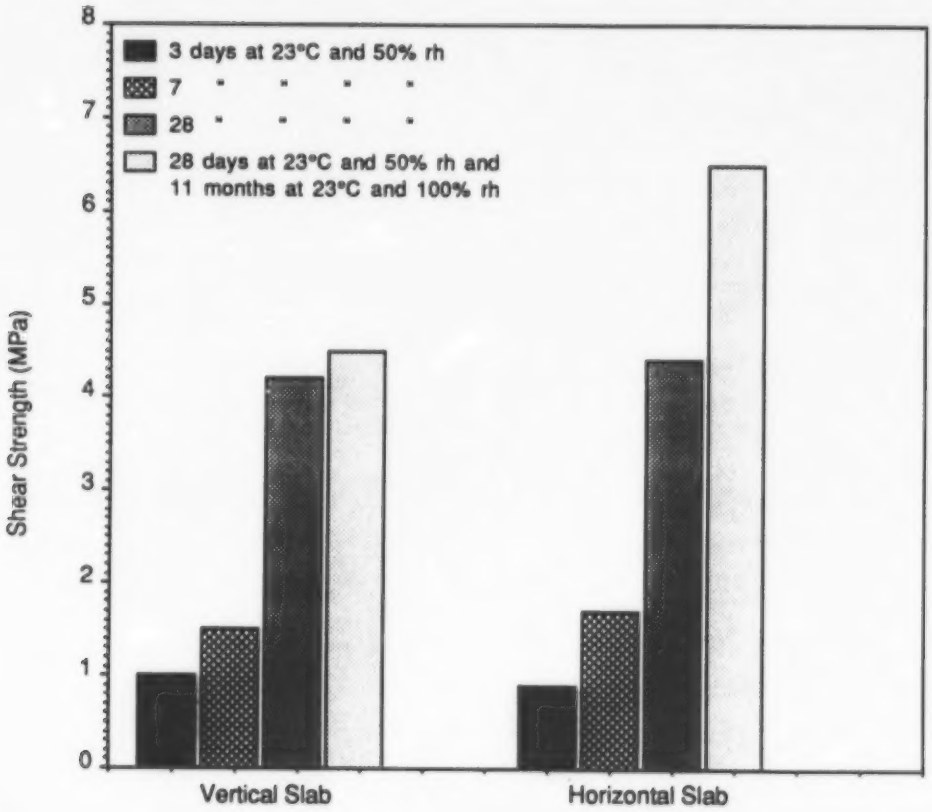

FIGURE D10

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 10

178446 RD
DEAN-G1

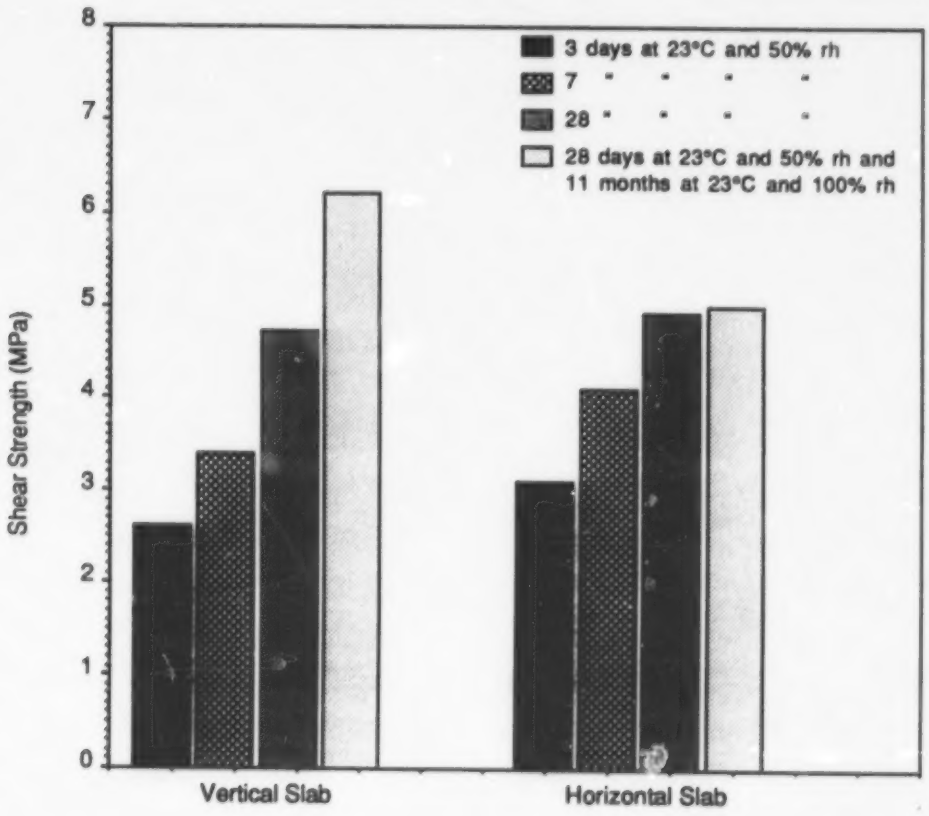

FIGURE D11

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 11

178596 RD
DEAN-01

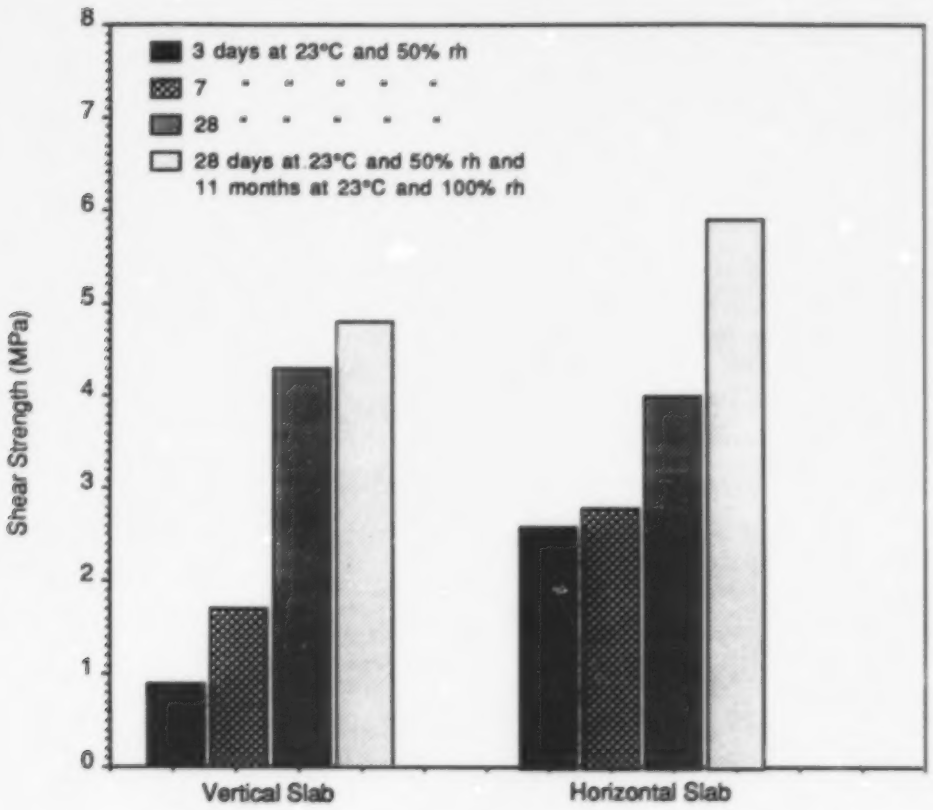

FIGURE D12

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 12

178444 RD
DEAN-G1

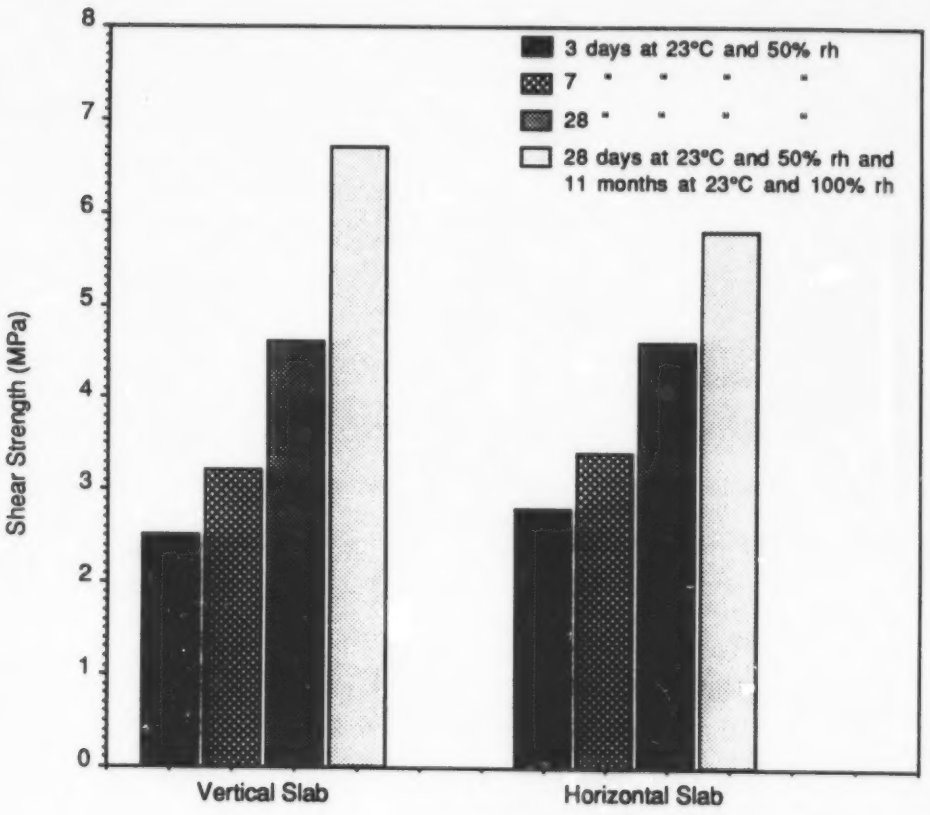

FIGURE D13

EVALUATION OF BONDING AGENTS - SHEAR STRENGTH
PRODUCT 13

178443 RD
DEAN-G1

APPENDIX E

USE OF EPOXY AND CEMENT-BASED BONDING AGENTS WITH CONCRETE

1.0 GENERAL

A bonding agent is used to achieve effective adhesion between the repair material and the existing concrete surface. Bonding agents help to wet out the concrete surface and provide good adhesion for the repair material.

The importance of the procedures will be more evident if consideration is first given to the qualifications of the repair as identified below:

1. It must be thoroughly and permanently bonded to the existing good quality concrete.

2. It must be sufficiently impermeable (but allow vapour transmission) to prevent moisture reaching the base concrete.

3. It must, after drying, be free of shrinkage cracks through which water could reach the supporting concrete.

4. It must be resistant to freeze/thaw cycles.

5. Where necessary, it must have good matching characteristics in relation to the base concrete.

2.0 PREPARATION OF CONCRETE SURFACES

The preparation of surfaces to receive bonding agents must be given careful attention because the bonding capability for a given application is primarily dependent on proper surface preparation. Since the ability of bonding agents to wet out the concrete surface varies, adhesion to concrete relies greatly on mechanical bond. A well bonded repair requires that base concrete to which bonding agent is to be applied has newly exposed surfaces free of any loose, unsound material. These surfaces should be meticulously cleaned and be at the required surface temperature when the bonding agent is applied.

The standard of surface preparation is fairly uniform for all types of bonding agents, because the existing concrete surface must always be thoroughly cleaned and mechanically sound. The method or combination of methods used for satisfactory surface preparation depends on the type, extent and location of application.

Thorough surface preparation is best achieved by bush hammering, use of medium to light weight air hammers equipped with appropriate cutting tools, abrasive blasting, high-pressure water jetting, or a combination of these methods. Surface preparation of the concrete should include the following:

(a) Removal of all loose, unsound and contaminated concrete.

(b) Removal of additional concrete from around and along reinforcement, where necessary.

(c) Cleaning of the substrate to remove all dust, oil and debris resulting from surface preparation operations.

(d) Roughening of the surface to give the adhesive more surface area and more interlock with the substrate.

(e) Formation of clean-cut edges to areas to be repaired, avoiding feather edges. Depth of the cut should be consistent with the type of repair.

(f) Natural or artificial drying of the concrete surface to a certain extent. A visible water film on the surface should be avoided as it will reduce adhesion.

- Where epoxy bonding agents are used, the concrete surface should be dry.

- Where cement-based bonding agents are used, the concrete should be saturated-surface dry.

It is important to realize that the moisture/temperature condition of the concrete surface should be controlled. For instance, surfaces should meet saturated-surface dry conditions for cement-based bonding agents and should be dry for epoxy bonding agents. For epoxies, the concrete temperature should be higher than the air temperature to prevent moisture from forming at the interface during curing of the resins. Since this is a practical problem in the field, epoxy bonding agents used should be moisture tolerant, with preferential wetting properties. If there is water in the pores and on the surface, it will prevent resin penetration and reduce mechanical interlocking.

Whatever surface preparation procedures are used, the result should be a surface abraded to an extent that at least small aggregate particles are exposed, but the surface should not be polished or unnecessarily rough and it must be free of all surface contaminants.

3.0 TEMPERATURE

The temperature of the concrete to be repaired should not be below 10°C. Ideally the temperature should be 20°C or higher.

Curing temperatures must be above 10°C.

All materials used and the concrete substrate should be maintained at a fairly constant temperature, otherwise the pot life of the bonding agents will vary and may cause considerable inconvenience.

4.0 BONDING AGENTS

A bond coat of cement slurry or latex-cement slurry can be applied to the prepared surfaces. Depending on the porosity of the concrete, it is normally necessary to dampen the concrete with clean water, to prevent any suction immediately before applying the bond coat; otherwise, the open time of the bonding coat will be too short. The slurry should be mixed to a smooth creamy consistency and applied as a uniform coat. The repair material must be applied while this bond coat is still tacky.

Epoxy resin bonding agents may also be used. Some resins are formulated to receive the repair material while the resins are still wet, whereas others require the materials to become tacky before application of the repair material.

Great care is required in timing the various operations and in ensuring compatibility of the materials being used.

5.0 METHODS OF APPLYING BONDING AGENTS

There are several methods for applying bonding agents as described below. Regardless of the method used, the bonding agent should be well worked into the surface of the concrete.

5.1 Spray Techniques

Airless spray is often used to apply epoxy bonding agents because minimal labour is involved and large areas of epoxy can be applied very quickly with little waste. The quantity of material pumped through the spray tip is relatively large, and it requires that the spray gun is passed steadily and rapidly over the surface.

Where access is difficult, airless spray is not generally recommended.

5.2 Brush and Roller Application

Paint rollers are used for fast and easy application of relatively thin layers of epoxy bonding agents over accessible areas, such as walls and floors.

Brush application for both epoxy and cement-based bonding agents is generally used in small, inaccessible areas.

5.3 Trowel Application

Thixotropic epoxies designed for high build and latex-modified cement bonding agents are applied by trowel in the same manner as conventional rendering material.

Manufacturers' recommendations for application should be followed, and the most cost effective and practical method for the individual site should be used.

6.0 PLACEMENT OF FRESH CONCRETE

General mixing and placing procedures for concrete or patching materials should be followed. Where cement-based bonding agents are used, the first layer of fresh concrete or patching material must be applied immediately after the bonding coat, while the latter is still wet. This is important because bond strength is reduced if the bonding coat is allowed to dry out. If delays occur, it may be necessary to apply a second coat of bonding agent, although some reduction in bond strength may still occur. Where more than one layer of repair material is required, the surface of the intermediate layers should be scratched and successive layers applied as soon as practical.

Where delays are inevitable, epoxy bonding agents having a longer open time than cement-based material should be used. Some epoxy bonding agents can be coated with coarse grit to provide a key for subsequently placed concrete.

7.0 CURING

Curing procedures should be designed to reduce temperature changes and prevent early drying of concrete or patching material. Reference should be made to the appropriate Canadian Standards Association (CSA) and American Concrete Institute (ACI) documents.

8.0 TEST PATCHES

Where practical, selected materials and techniques should be experimented with using small test sections of repair to identify problems and to estimate performance. Such extra measures require additional time and cost initially, but will result in overall savings and better performance.